THE
JOURNAL OF POMOLOGY
AND
HORTICULTURAL SCIENCE

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Vol. X

1932

HEADLEY BROTHERS
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PRINTED AND MADE IN GREAT BRITAIN BY HEADLEY BROTHERS, ASHFORD, KENT.

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FURTHER OBSERVATIONS ON THE HABITS OF THE RASPBERRY BEETLE (*Byturus tomentosus* Fabr.) WITH SPECIAL REFERENCE TO THE CONTROL OF THE PEST BY MEANS OF DERRIS.

By W. STEER,
East Malling Research Station.

INTRODUCTION.

A STUDY of the life history and habits of the Raspberry and Loganberry Beetle (*Byturus tomentosus* Fabr.) was begun in August, 1927, with a view to finding a stage at which the pest might most effectively and economically be attacked. Reference has been made in a previous report (7) to promising indications obtained with a double spraying method of control based on a consideration of the larval habits.

Following Lees' attempts to control this beetle in 1917 (2) with a paraffin-nicotine-soap emulsion used against the adults, and in 1919 (3) with various methods of cultivation, Lees and Peren (4, 5, 6) found that they could reduce the infestation by three sprayings of lead arsenate during the blossoming period. The applications were made in their 1921 and 1922 trials when approximately one-third, two-thirds, and all the blossoms were fully open, and resulted in a reduction of the infestation by about three-quarters.

More recently Walton (11, 12) has obtained excellent results with three sprayings of a specially prepared Pyrethrum extract, his applications being made at the same stages of flowering as those of Lees and Peren. Apparently this triple spraying method is chiefly directed against the adult beetles, many of which are actually recorded as paralysed thereby (9, 11) and ultimately dying.

THE DOUBLE SPRAYING METHOD.

Observations upon the life-history of the pest at East Malling suggested the possibility of reducing the number of spray applications recommended by Peren (6) by directing the attack solely against the young larvae. It was found that on hatching the larvae crawl over and feed on the surface of the hard green drupels for some considerable time before they bore into the fruit. The duration of the flowering and, consequently, of the egg-laying and hatching periods seemed to preclude the use of a simple contact spray (though this conclusion may require revision in the light of recent observations) and the object aimed at in spraying, therefore, was to provide a deposit on the fruits which would be toxic over a sufficiently long period to the young larvae. A trial of Derris and Arsenate of lead on raspberries in 1928 suggested that a single spraying just before hatching begins is insufficient, and that more than one application is necessary.

In 1929 Lead Arsenate gave excellent results when used on a double-spraying basis, but the persistent poisonous deposit left on the fruits caused its use to be discontinued and recourse to be had to non-arsenical insecticides only.

Very promising indications were obtained (7) in two seasons' trials (1928 and 1930) but less promising in a third season (1929) with a proprietary Derris preparation, when used against the larvae.

In order to check these results and to obtain further information as to the optimum dates for spraying it was decided to carry out extended field trials on both loganberries and raspberries combined with detailed observations on the hatching and subsequent behaviour of the larvae.

THE TIMING OF THE SPRAY.

With the " double-spraying " method it was thought desirable to make the first application just before hatching began. Since the egg stage lasts ten to twelve days this would be some ten days after egg-laying begins. Watch was kept for the first appearance of eggs and on June 1st a few were found in loganberry flowers. On this date some loganberry but very few raspberry flowers were open and very few adults containing fully developed eggs could be found. On June 2nd a few eggs were found on raspberries attached to stems and petioles.* The date of the first application was therefore fixed for June 10th. The fact that no larvae were found, despite careful search, before June 12th, suggests that this date was well chosen.

The optimum interval which may elapse between the two sprayings depends on the length of time the first application remains effective and on the duration of the hatching period. Trial II was especially designed with a view to obtaining preliminary information on this point.

SPRAYS AND DUST USED.

The writer wishes to record his indebtedness to Dr. F. Tattersfield of the Rothamsted Department of Insecticides and Fungicides for his help in connection with the two forms of Derris used in the trials. Without his aid it would not have been possible to give such information as to their chemical composition as is given below.

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* As far as the writer is aware eggs of *Byturus tomentosus* have not previously been observed in such situations. These eggs were placed in the laboratory and were all hatched by June 15th. A single egg was found at a much later date (July 3rd) attached to a flower bud of Himalaya Berry. Another apparently unrecorded fact was observed on raspberries late in June—the feeding of larvae in the tips of young canes—further reference to which is made in dealing with trial IV.

Proprietary Derris.—When the need for a non-arsenical spray first arose a readily available Derris preparation was used, and applied at a purely arbitrary dilution (2 lbs. to 40 gallons of water). In subsequent experimental work it was felt desirable to continue its use for the sake of uniformity, inasmuch as the wash was regarded primarily as an indicator to confirm observations made on the habits of the larvae, and to avoid the delay which the standardization of a home-made article might entail.

This preparation is a proprietary one containing finely ground Derris Root and powdered soap in undeclared amounts, and on mixing with water gives a suspension of Derris in soap solution.

The material used in the 1931 trials was found to have a rotenone content of 0·6 to 0·7 per cent and to contain a high proportion of soap. At the dilution used in the trials the spray would have a rotenone content of 0·003 to 0·0035 per cent.

No tests have yet been made with other wet Derris sprays or with other dilutions in the East Malling trials, but such tests will form an important part of future experiments.

Derris Dust.—The home-made Derris dust used on raspberries in Trial III and on a few rows of loganberries in a commercial plantation, was again used primarily against the larvae, and consisted of 5 per cent by weight (a purely experimental proportion) of finely ground Derris Root and 95 per cent of China Clay. The Derris Root was purchased commercially at 2s. per pound from a firm of spice and general produce importers, and the China Clay obtained from a firm of insecticide manufacturers at 4s. 3d. per cwt.

The method of mixing was admittedly imperfect—the materials were stirred and shaken up, a pound at a time in a pail, and further mixed by shaking through a 30 mesh sieve.

The rotenone content of the ground Derris was 1·8 to 1·9 per cent. The dust as applied would therefore contain 0·09 to 0·095 per cent rotenone. As a wet spray such a sample of ground Derris used at 2 lbs. per 100 gallons of water, plus a sufficiency of soap might possibly approximate to the diluted proprietary preparation already described.

The dust will serve as a basis for further investigations into the optimum dilutions of a Derris of known rotenone content.

Very little information is available as to the exact effect exercised by Derris on insects. Although proved to act as a contact insecticide, there is some difference of opinion as to whether it also possesses stomach-poison properties. Kelsall and others (1) doubt whether it possesses such properties and found it useless as a poison bait for cutworms. From his experience with *Byturus* *tomentosus* the writer is inclined to agree with their view, but, whatever may be its precise action, there seems no doubt that it is highly toxic to the larvae of this beetle, and that it has both a direct and a residual killing effect.

Pyrethrum.—The proprietary Pyrethrum preparation which proved promising up to a point in the previous season's work was again used in 1931 as no facilities were available for making up an emulsion exactly according to the method described by Tutin (9, 10). This was included in the hope that it might be as effective in the double spraying method against the larvae as the Long Ashton Pyrethrum had proved in a triple spraying method against the beetles in the West country (11, 12).

However, the mediocre results obtained with this wash in 1931 suggest that it was not up to the standard previously used, or recommended by the Long Ashton workers. Although detailed figures were obtained it is felt that no useful purpose would be served by their general inclusion. Apparently pyrethrum washes proved to be very variable chemically during the season of 1931, and the results obtained with this proprietary preparation might prove misleading.

Nicotine.—The nicotine and soap spray used in Trial IV was intended purely as a contact spray for the larvae. Observations having suggested that a late application of a contact insecticide (not necessarily possessing residual properties) might reduce the infestation, the most popular and readily available insecticide of this type was chosen (see page 13).

1931 TRIALS.

Trial I.—Double-spraying method on loganberries.

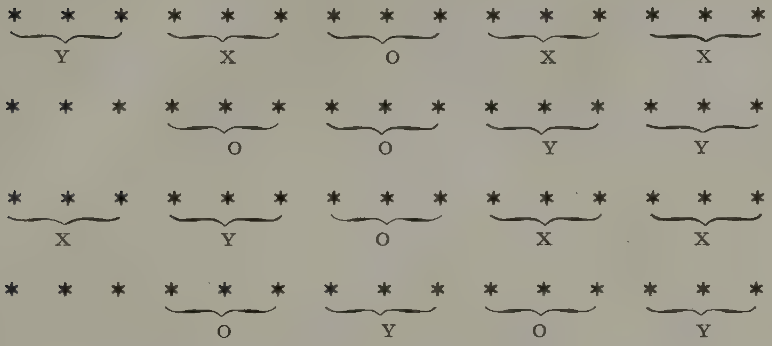
Lay-out of Trial.—Four rows each consisting of fifteen bushes were available and subsequently proved to be very heavily infested. A spraying trial against Cane Spot (*Plectodiscella veneta*) was also carried out on the same bushes by Mr. R. V. Harris, but the arrangement of the plots, for which Mr. T. N. Hoblyn was responsible, was such that it is possible to state with certainty that the lime-sulphur applied in March for Cane Spot affected neither the incidence of the pest nor the action of the sprays used against it.

Two spray treatments only were given and it will be seen from the accompanying plan that units of three bushes were used and that each treatment was repeated six times.

The proprietary Pyrethrum extract was used at the same strength as in the 1930 trial (2 gallons to 100 gallons water plus 9 ozs. caustic soda). It emulsified readily and wetted the flowers and fruits well, but not so well as the proprietary Derris-soap preparation.

The latter was used at the dilution of 2 lbs. to 40 gallons of water. Supplies were obtained commercially. It mixed well and excellent wetting was obtained.

Plan of Trial I.



Key. X = Proprietary Pyrethrum (two sprayings), June 10th and 20th.
Y = Proprietary Derris ,, ,, ,,
O = Unsprayed Controls.

Application of Sprays.—The two sprayings were given on June 10th and 20th. Although originally the main object of this experiment was to compare the relative toxicities to the beetle larvae of the two preparations at the strengths used, it also succeeded in demonstrating for the third season the high toxicity of a double application of the Derris preparation.

A Cascade hand pump supplying one nozzle and working at approximately 200 lbs. pressure was used, and spray drift to neighbouring plots was avoided by the careful use of a hessian screen.

Half to two-thirds of a gallon of spray per bush was required to ensure thorough wetting of the flowers and fruits.

At the time of the first application the weather was dull with occasional fine rain, but insufficient to wet the leaves to any extent. No larvae were found, but adults and eggs were abundant. When the second application was made adults were less in evidence, but eggs were abundant and larvae numerous. Some flower buds had still to open.

Observations.—Subsequent observations showed that hatching was apparently normal on both sprayed and control bushes and larvae could be found in abundance. In fact until the fruit actually began to ripen it was very difficult to detect any differences at all between sprayed and control plants.

When picking began random samples of 100 berries were taken from each plot and the number infested recorded for each sample with the aid of a mechanical hand counting machine. Thus 600 berries from each of the three treatments were examined at each sampling. Eleven such samples were made, coinciding as nearly as possible in date with the commercial pickings. The total number of berries thus recorded was 19,800. The percentage infestation is shown in Table I.

Commercial pickings of the whole of the crop were made in the ordinary way except that the pickers were asked to grade the crop roughly into marketable and unmarketable fruit. Records of the weights of these two grades were kept and are summarized in the histograph (Diagram 3, page 18).

TABLE I.

Trial I.—Loganberries. Mean Infestation per sample of 100 *Berries.*

(a) Each picking. (S.E. = 2·30. Significant difference = 6·5.)

Date of Samples.	Treatment.	
	Derris.	Controls.
10/7/31	23·2	97·5
14/7/31	16·8	94·8
16/4/31	12·8	93·7
18/7/31	19·8	92·8
21/7/31	19·0	83·3
24/7/31	20·5	66·8
27/7/31	11·8	54·8
29/7/31	10·3	48·5
31/7/31	11·2	40·0
3/8/31	8·0	30·0
7/8/31	7·5	27·5

(b) Eleven pickings. (S.E. = 0·69. Significant difference = 1·96.)

Treatment.	Derris.	Controls.
Mean per sample	14·6	66·3

Discussion of Results.—It will be seen that a very good control of raspberry beetle was obtained with the proprietary Derris preparation. Fruit from Derris sprayed plots was substantially free from beetle whilst fruit from control plots was, until towards the end of the season, quite worthless and unmarketable. Fruit sprayed with the proprietary Pyrethrum held an intermediate position. Random samples of fruit from the three treatments were on various occasions submitted without labels to a number of people who invariably and without hesitation placed them in the above order.

Table I(a) shows that the infestation on unsprayed plots began at 97·5 per cent and gradually fell to 27·5 per cent by the end of the season. This is the usual tendency on loganberries under our conditions, but not on raspberries. Loganberries do not " plug " when picked and the larvae are accordingly removed with the fruit. When raspberries are picked, however, it has been observed that many larvae remain in the " plugs " which are usually left on the canes, and so may infest other berries. This would account for the difference in the infestation curves of raspberries and loganberries.

Table II summarizes the information obtained from Trial I.

TABLE II.

Trial I.—Summary of Results.

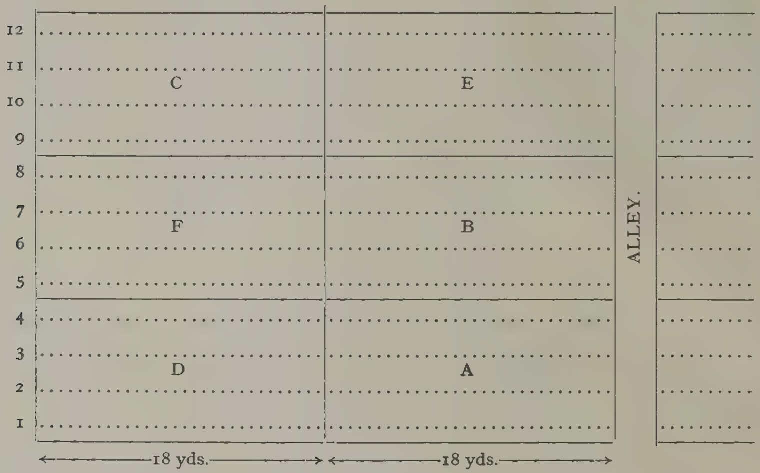
Treatment.	Average infestation.	Total crop.	Weight marketable.	Estimated cwts. per acre marketable.
Unsprayed ..	66·3 per cent.	118 lbs.	23·8 per cent.	8·3
Derris	14·6 ,,	224 lbs.	77·7 ,,	51·8

Effect on Weight of Crop and Fruit Quality.—Random samples showed great differences in weight between equal numbers of berries from sprayed and unsprayed plots. The weight ratio of such samples from the Derris and control plots is shown in Diagram I (page 17). Infestation by the beetle larvae, besides producing a proportion of small misshapen berries, causes loss of weight by evaporation through ruptured tissues and thus reduces the weight of the fruit. The average number of berries per pound of ripe fruit over the whole of the picking season worked out at—Controls 176 and Derris 127.

Suggestions for Control Measures.—The results of the 1931 and previous seasons' trials show that a good commercial control may be obtained on loganberries by two applications of a Derris preparation. One spraying should be given ten to fifteen days after the first blossoms open followed by a second spraying about ten days later. Under most Kentish conditions these dates would approximate to June 10th and 20th. The experience of 1929 suggests that *it is advisable always to use fresh materials.*

Trial II.—Double-spraying method on raspberries.

Lay-out.—Trials II and III were carried out on an acre of four year old Lloyd George raspberries, consisting of twelve long rows. The accompanying plan shows the arrangement of the six treatments in one of the four randomized blocks of Trial II. The dotted lines represent rows of raspberries and the continuous lines plot boundaries.



Explanation of Treatments.

A=Pyrethrum—3 sprayings—June 4th, 10th-11th and 18th.
B= ,, —2 ,, —June 10th-11th and 17th.
C= ,, —2 ,, —June 11th and 23rd.
D=Derris —2 ,, —June 11th and 18th.
E= ,, —2 ,, —June 10th-11th and 23rd.
F=Unsprayed controls.

Six different treatments (including unsprayed controls) were employed in this trial, the main objects being

1. to compare triple and double spraying, and
2. to obtain information as to the optimum dates for the second application with the double spraying method.

In treatment A the Pyrethrum spray was applied when approximately one-third, two-thirds, and all the blossoms were open. The date of the first spraying of the other treatments was calculated to be approximately ten days after egg-laying began. The time that elapsed between the two sprayings of these treatments was seven days in the case of the shorter interval series (B and D) and twelve days in the case of the longer interval series (C and E).

It is unfortunate that the proprietary Pyrethrum which proved to be only partially effective in Trial I was used for the comparison of triple and double spraying. This proved no more effective with the three applications than with two. However, the Derris treatments yielded conclusive data on the second point on which information was sought—the respective merits of a short and a long interval between the sprayings.

Application of Sprays.—The Derris preparation was the same as that used in the loganberry trial and was used at the same strength. A Cascade hand pump sprayer supplying one nozzle and working at about 200 lbs. pressure was used. Alleys were cut across the rows at intervals for greater ease of manipulation. No screens were used, but no appreciable amount of spray drifted beyond one row. The portions of the rows from which records were ultimately taken received no spray drift as far as could be judged.

The weather throughout the spraying period was on the whole favourable. June 10th was a dull day with some drizzle culminating in showers sufficiently heavy to stop spraying about 4 p.m. No appreciable amount of rain fell on any of the other spraying dates and only 0·27 inches of rain was measured between the beginning of spraying on the 10th and the beginning of picking.

Observations.—The Derris wetted both flowers and fruits well and had no deleterious effect on the foliage or crop.

Picking began on July 6th and eight pickings were made. At each picking two random samples of 100 berries were picked " with the plug " from each plot (one sample from each of the two middle rows) and the numbers of infested fruits recorded. Thus 800 berries of each of the six treatments were examined at each picking, making a total for the season of 36,000 fruits in this trial alone. Each picking and counting of Trials II and III took eight to nine hours to complete. The size of the samples was reduced by half in the final picking, since by then it was difficult to obtain a random sample of 100 from some of the control rows. Although no further records were taken after July 27th there was still an abundance of excellent fruit on all the Derris plots.

The results are set out in Table III and compared with the results of Trials III and IV in Diagram 2 (page 17).

Discussion of Results.—It will be seen that two sprayings of the Derris preparation practically eliminated the pest, and that the effect was maintained throughout the picking season.

The close approximation of the results of the two Derris treatments (with shorter and longer intervals) indicates that there is considerable latitude in the time which may be allowed to elapse between the two sprayings. The differences (Table III), although just significant, are not sufficiently great to justify the recommendation of a longer as against a shorter interval. In a small raspberry spraying trial carried out at East Malling in 1928 a single spraying of Derris

TABLE III.

Trial II.—Raspberries. Mean Infestation per sample of 100 *Raspberries.*

(a) Each picking. (S.E. = 2·16. Significant difference = 6·12.)

Dates of samples.	Treatment.		
	Derris. (Short interval.)	Derris. (Long interval.)	Controls.
6/7/31	6·2	7·7	80·2
9/7/31	5·2	5·9	70·9
11/7/31	5·1	2·1	72·1
13/7/31	5·5	3·9	80·0
15/7/31	5·4	4·2	85·0
17/7/31	6·2	2·9	84·2
23/7/31	10·4	4·5	80·9
26/7/31	11·5	6·0	72·7

(b) Eight pickings. (S.E. = 0·765. Significance difference = 2·16.)

Treatment.	Derris.		Controls.
	Short interval.	Long interval.	
Mean per sample ..	6·95	4·66	78·27

a few days before hatching began (i.e., roughly corresponding to the first spraying of the 1931 treatments) reduced the infestation from 36·5 per cent to 19·2 per cent.

Suggestions for Control Measures.—In view of the results obtained with the Derris preparation, experimentally in Trial II and commercially on a four acre block of Lloyd George, the following spraying schedule is suggested :

Raspberries should be sprayed about ten days after the beginning of flowering and again seven to fifteen days subsequently. There is considerable latitude where raspberries are concerned and the approximate dates (under East Malling conditions) may be regarded as June 10th to 15th for the first, and June 20th to 25th for the second application. About 500 gallons of spray per acre will be required for each application to raspberries of average vigour, and care must be taken to wet the whole of the flowers and fruits.

Trial III.—Derris Dust.

Lay-out.—This experiment consisted of a trial of the home-made Derris dust already described, and was carried out on eight rows of Baumforth A raspberry. The chief object was to establish a basis for future work on the use of Derris of known composition.

The rows were about 45 yards long and were divided for dusting purposes into three blocks of 15 yards.

Application of Dust.—Application was by means of a Niagara rotary hand blower on June 10th, 17th and 23rd. The Derris dust was applied to the central block, China Clay alone to the southern block and the remaining block received no treatment at all. On each occasion dusting was begun about 5.30 a.m. under moderately suitable weather conditions. The plants were dry and the wind slight. Slight rain fell during the day of the first dusting, culminating in rather sharp showers in the late afternoon. The dust was still visible in the flowers and on the leaves after rain had fallen.

The rate of dusting was approximately 100 lbs. per acre at each application.

Observations.—Adult beetles did not seem to be affected by the dust to any extent, and could be found crawling in well dusted flowers or walking about in the plants with deposits of dust on their backs.

When the fruit began to change colour on ripening the dust deposit was very plainly seen. This is a very serious disadvantage where dessert fruit is concerned.

When records were taken three random samples of 100 berries were made at various spots in each block, care being taken to avoid those portions of the plot where drift may have occurred. Thus 300 berries were examined from each treatment at each of the seven pickings, making a total of 6,300 berries by the end of the season.

The results are shown in Table IV and on a comparative basis with Trials II and IV in Diagram 2 (page 17).

TABLE IV.

Trial III.—Raspberries. Percentage Infestation.

Date of Sampling.	Treatment.			
	Derris Dust.	China Clay.	Nil.	Mean of 2 controls.
7/7/31	12	54·3	53	53·7
10/7/31	7·7	46·7	46·7	46·7
13/7/31	9	52	40·7	46·3
15/7/31	5	54·7	37·7	46·2
20/7/31	9	48·3	43	45·7
22/7/31	8	46·7	38·7	42·7
27/7/31	8	28·7	31·3	30
Average	8·4	47·3	41·7	44·4

Supplementary Observations.—Some confirmation of this result was provided by a supplementary trial on a commercial loganberry plantation near Brenchley, Kent, carried out through the courtesy of Mr. Darnley Glover and with the aid of Mr. W. G. Kent, the County Horticultural Adviser.

The dust, which has already been described, was applied on June 12th, 23rd and 29th with an efficient hand dusting machine. It was applied sparingly owing to the fear of a possible unsightly deposit on the fruits (12). Various unexpected delays were responsible for the rather late date of the second and third dustings and two rows did not receive the third application at all.

The lay-out was as follows : Five rows control, two rows dusted, two rows control, two rows dusted.

The percentage infestation shown by a few small random samples was as follows :

TABLE V.

Date of samples.	No. counted per plot.	Controls.	Derris Dust.	
			Three times.	Twice.
11/7/31	350	47·4	14·3	11·3
16/7/31	200	53	34·7	23
25/7/31	200	61	46·5	37
28/7/31	200	71·5	42·5	50
Average	—	58·2	34·5	30·3

A proprietary dust containing an undeclared percentage of Derris Root was applied commercially to another part of the same plantation. More than twice as much dust was used here as in the experimental rows, and a very considerable deposit was left on the fruits. Detailed counts were not made, but the infestation appeared to be rather lower than in the rows dusted experimentally.

Discussion of Results.—The Derris dust reduced the infestation considerably on raspberries in Trial III (from 44·4 to 8·4 per cent) and by nearly a half on loganberries in the supplementary commercial trial.

By reason of the lay-out and the small size of the samples, the same reliability cannot be attached to the figures of this supplementary trial as to the figures of the other, better controlled experiments. However, the results seem sufficiently definite to show that Derris dusts are well worth further investigation. They also afford a basis for the further study of sprays and dusts of known rotenone content.

The fact that the canners who bought the crop of the Brenchley plantation would accept the fruit from the dusted rows but not from the control rows serves to strengthen these conclusions.

It will be noticed that this plantation showed a tendency (rather unusual in loganberries) for the infestation to become heavier as picking progressed. This may possibly be connected with the very heavy applications of lead arsenate which the whole plantation received before blossoming began.

A serious disadvantage of using this form of Derris dust is the white deposit (due to the China Clay " carrier ") which is retained by the fruit. This may possibly be overcome by the use of a different " carrier " or by the incorporation of a suitable dye.

If satisfactory results could be obtained with it, a dust would have the advantage over a wet spray in ease and rapidity of application.

Trial IV.—Single spray on raspberries.

Object of Trial.—Observations showed that in 1931 very few larvae had entered raspberry fruits up to the time that the first Lloyd George berries began to turn colour (i.e., the end of June). Only a few specimens were found in the " plugs " and those only in the occasional ripening fruits.

Furthermore an examination of the canes revealed the presence of large numbers of very small larvae in the tips of the young canes. These were feeding on the tenderest unopened leaves and mining in the soft stem tips. As far as the writer is aware this habit has not been recorded before. It is not certain whether these larvae were from eggs laid on the fruits or from eggs laid on the leaves and stems. It is suspected that many of them were probably from the former, since eggs laid on the leaves and stems were not numerous and the numbers of larvae to be found on the berries at the end of June did not seem commensurate with the large numbers of eggs previously observed, or with the subsequent heavy infestation of the ripe fruit.

In view of the exposed condition of the larvae, either on the fruits or on the young leaves, at this period it seemed feasible to suppose that a large proportion of them might be destroyed by a single application of a good contact insecticide such as nicotine.

Lay-out and Application.—Two plots similar in size to those of Trial II were sprayed on July 1st with nicotine and soft soap (8 ozs. nicotine and 10 lbs. soap to 100 gallons of water). An attempt was made to secure thorough wetting

TABLE VI.

Trial IV.—Raspberries. Percentage Infestation.

Dates of Sampling.	Treatment.	
	Nicotine.	Controls.
6/7/31	32·2	54·0
9/7/31	26·8	56·0
11/7/31	27·2	65·5
13/7/31	37·5	71·5
15/7/31	34·8	82·8
17/7/31	40·0	88·8
23/7/31	52·5	77·8
26/7/31	45·5	71·0
Average	36·5	70·9

of the fruits and the tips of the young canes. At the time spraying was carried out several fruits were ripe, and picking actually began six days later.

Observations.—Records were taken in precisely the same manner and on the same dates as in Trial II. These are embodied in Table VI and on a comparative basis with Trials II and III in Diagram 2.

Discussion of Results.—From this it appears that one spraying with nicotine and soap six days before picking began, reduced the infestation by almost a half (from 70·9 to 36·5 per cent) and opens a further line of investigation—the possibility of attacking the larvae at a rather later stage than was aimed at in the double spraying experiments. This depends on the larvae remaining exposed, either on the surface of the berries or in the tips of young canes, until a late stage in the development of the fruit. Thus it may prove possible to achieve satisfactory results with one or two nicotine sprayings or with a single late Derris spraying.

THE ECONOMICS OF SPRAYING RASPBERRIES AND LOGANBERRIES.

Four acres of Lloyd George raspberry growing on the Station were sprayed commercially with the Derris preparation used in the trials and provided useful cost of spraying data.

The plantation was situated only a few hundred yards from Trial II, where the average infestation on unsprayed plots was nearly 80 per cent. The crop proved to be substantially free from beetle, much freer in fact than in previous seasons, whilst raspberries elsewhere on the Station were more heavily infested than ever before.

The first spraying was given on June 12th-13th and the second June 29th-30th. A 2½ H.P. machine supplying six nozzles at a pressure of about 150 lbs. was used. Two days were taken to spray the four acres, and 2,000 gallons of spray used.

The expenses were as follows for each spraying :

	£	s.	d.
Application—Six men, 15 hours at 9d.	3	7	6
Mixing, etc.—One man, 15 hours at 9d.		11	3
Carting Water—One man, 6 hours at 9d.		4	6
One horse, 6 hours at 5d.		2	6
Petrol—3 gallons at 1s. 3½d. per gallon		3	10½
Spray Material—100 lbs. at 2s. 1½d. per lb.	10	12	6
Water—2,000 gallons		7	0
Total	£15	9	1½

Total cost, 4 acres = £15 9s. 1½d.
Cost per acre = £3 17s. 3½d.

Thus the cost of spraying raspberries of average vigour *twice* with this particular proprietary article may be reckoned as about £7 15s. per acre, exclusive of wear and tear of machinery.

Apart from any possible increased yield, raspberries would have to fetch an extra half-penny per pound on a 2 ton crop to show an appreciable profit over the cost of spraying. The real advantage of spraying lies in the increased proportion of first class punnet fruit and the decreased proportion of fruit fit only for jam or even unsaleable.

Exact figures are not available for the cost of spraying loganberries but with a similar outfit the cost of application would probably be about the same as for raspberries. Rather less spray material would be used on a 12 ft. by 6 ft. plant—300 gallons per acre can be taken as the minimum—and the total cost of two applications of this Derris preparation would probably be in the neighbourhood of £6 per acre.

Loganberry spraying, even with the somewhat expensive form of Derris used in the trials, is definitely an economic proposition where the pest is troublesome. The profit per acre as a direct result of such spraying can be readily calculated in the case of Trial I. The increased yield of marketable fruit was over 2 tons per acre. Assuming a net price of 3d. per lb. for this fruit, and reckoning the cost of spraying at £7 per acre (a high estimate), the net increased profit would be at the rate of about £50 per acre.

Where the length of the rows is not unduly long the sprays could be more cheaply applied by means of a horse-drawn power machine, supplying two nozzles.

Further proposed investigations may lead to a reduction in the cost of spraying. These include trials of cheaper forms and greater dilutions of Derris, Derris dusts and the use of one spraying instead of two.

The writer is indebted to Mr. T. N. Hoblyn for valuable assistance in planning Trials I and II, and for the statistical examination of the results.

SUMMARY.

Observations upon the life history of the Raspberry and Loganberry Beetle (*Byturus tomentosus* F.) showed that, after hatching, the larvae remained exposed for a considerable period before entering the berries. This suggested the possibility of attacking the pest in the larval stage, and of reducing the number of spray applications previously recommended (i.e., three).

A proprietary Derris preparation was used in 1931 according to a double spraying method which had given promising indications in previous seasons' trials.

The sprays were applied ten days after the first eggs were observed and again a week to twelve days later. Derris gave a very efficient control. The average infestation of loganberries was reduced from 66·3 to 14·6 per cent, and of raspberries from 78·3 to 5·6 per cent. The weight of marketable fruit was in the former case increased from 8·3 to 51·8 cwts. per acre.

The actual weight as well as the quality of the crop is shown to be affected by the damage done by the larvae.

A home-made Derris dust of known rotenone content was given a preliminary trial, and was sufficiently successful to form the basis for a further study of both Derris dusts and wet sprays of known rotenone content.

The possibility of using a single delayed contact spray (such as Nicotine) against the larvae was tested and is discussed.

The cost of the various spraying operations are discussed and suggestions made for the most suitable times for spraying with Derris.

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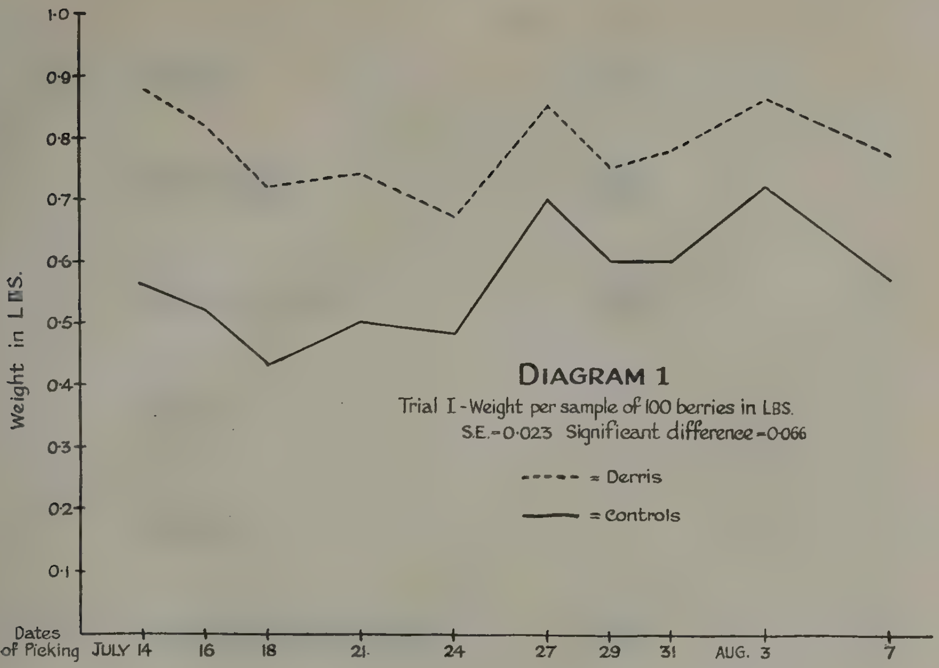


DIAGRAM 1

Trial I - Weight per sample of 100 berries in LBS.
S.E.=0·023 Significant difference=0·066

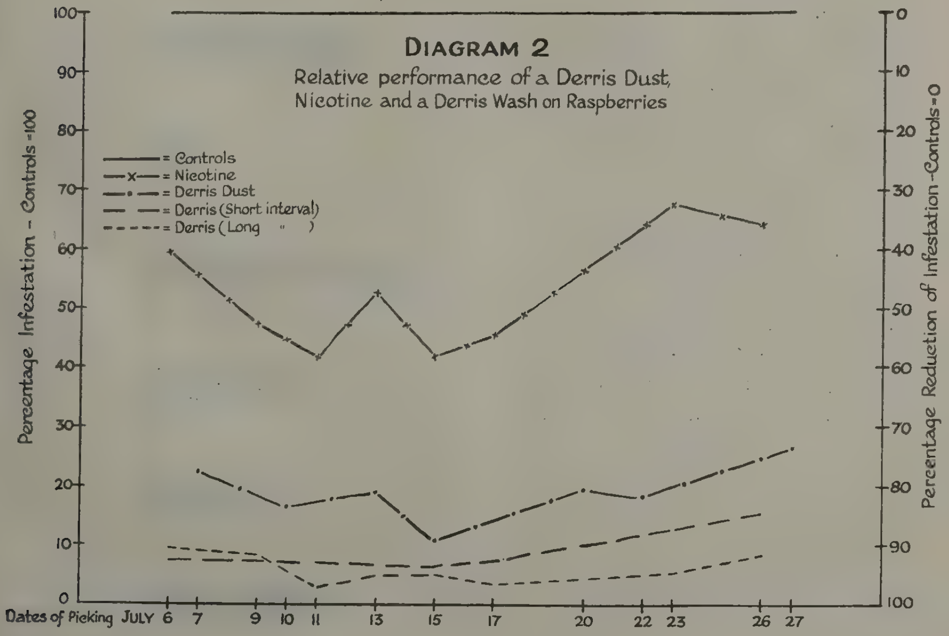
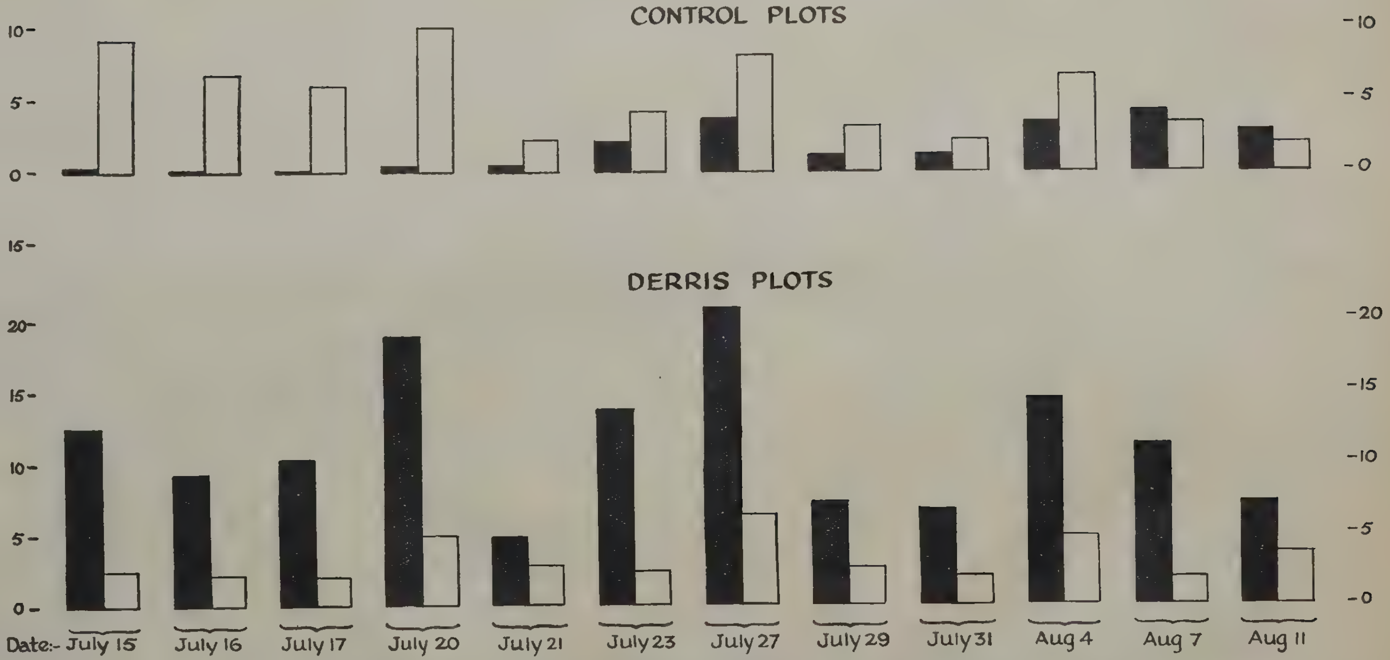


DIAGRAM 2

Relative performance of a Derris Dust, Nicotine and a Derris Wash on Raspberries

DIAGRAM 3

Trial I - Comparative yields as shewn
by twelve commercial pickings.



Shaded columns represent weight of marketable fruit in LBS.
Unshaded " " " unmarketable " "

THE INFLORESCENCES OF APPLE TREES.

THEIR USE IN THE IDENTIFICATION OF VARIETIES.

By R. T. PEARL, B.Sc.,
South-Eastern Agricultural College, Wye, Kent.

The value of descriptions of apple varieties by their characteristics at flowering time deserves wider recognition than at present is the case. Whilst the fruit characters are principally, sometimes exclusively, relied upon to provide a description of the variety in systematic records, it is probable that the flower of the apple offers a somewhat easier and more certain means of identification of the variety in the field than any other part of the tree. The number of organs and the range of form in the inflorescence is much less limited than is the case with foliage and branch characters (10), moreover inflorescence characters seem to be more constant than other characters under varying external conditions.

Whilst the majority of the standard pomologies have omitted any reference to the flowers of apple varieties, floral descriptions are by no means an innovation and an historical review is given elsewhere (11). Many of the characters described in the present paper have been made use of by certain pomologists, notably by Duhamel du Monceau (6), but in the past descriptions have usually been brief and lacking in uniformity, thus making varietal comparisons very difficult. Bunyard (2) gives an account of the characters used in the description of apple flowers and discusses their relative value in the identification of varieties. His paper forms an introduction to the subject of the utmost value : the points considered are principally those employed by Duhamel du Monceau (6, 12) but with the addition of flower bud colour introduced by Bunyard himself. Bunyard emphasizes the value of flower bud colour, the relative length of stamens and styles and the characters of the styles for purposes of identification. Farrell (7) considers the characters of the stamens and styles to be of chief importance.

The present paper is based upon observations made over a period of about five years on about sixty different varieties. On account of the shortness of the flowering season, the study has been mainly confined to the vicinity of Wye, Kent (particularly the College plantations and the walled fruit garden at Olantigh) but sporadic observations in more distant districts have served to confirm the local data.

CHARACTERS USED IN IDENTIFICATION.

In a general way the following characters have proved most consistently useful in the identification of apple varieties during flowering :

Inflorescence.—Season of flowering. Arrangement of flowers, length and stoutness of pedicels.

Flower-bud and Flower.—Flower-bud colour. Flower pose (cupping and overlapping of petals), texture of petals; pose of sepals; shape and margin of petals; pose of stamens; relative length of styles to stamens, length of style column, pubescence of styles and style column.

Young Spur-leaves.—Shape, colour, shininess, upper surface, leaf-pose.

Certain other characters are of occasional value in identifying specific varieties: these are described in more detail in the subsequent consideration of the various parts of the inflorescence. As a rule for purposes of identification, the inflorescences opening earliest and also those opening after general flowering has abated should be disregarded: they tend to be abnormal in several respects. Inflorescences from terminal buds on leaders, stout brindilles or in positions likely to be associated with vigorous growth should also be avoided.

I. VARIETAL CHARACTERISTICS OF THE INFLORESCENCE.

(a) *Season of Flowering.*—Varieties are fairly readily classified as early, mid-season and late-flowering, but some minor seasonal differences in the relative order of flowering may be found in different parts of the country (4). Nutritional conditions in the soil may influence the season of flowering: Wallace's results (13) obtained from pot experiments with the apple and other fruit trees are suggestive, for he shows that the omission of nitrogen or phosphorus from nutrient solutions delays the time of opening of the blossom buds, whereas the omission of potassium frequently advances it. Hatton and Grubb (8) show that pruning and rootstock type influence the period of blossoming: in their experiments unpruned trees blossomed earlier and for a longer period than pruned trees, and with certain exceptions trees on the more dwarfing rootstocks were as a rule earlier flowering than those of the same variety worked on the more vigorous stocks. They also point out an important difference in the time of flowering of different classes of fruit buds: terminal fruit buds on long shoots (e.g. brindilles) are usually early flowering, spur fruit buds are mainly mid-season, whilst axillary fruit buds are mostly late flowering for the variety. This may be the explanation of the successional flowering observed by Bunyard (2), since the phenomenon does not occur invariably in the varieties he mentions. It is certain that the duration of flowering of different trees carrying a full crop of fruit-buds varies considerably even under similar climatic conditions, but to what extent this is a true varietal difference remains undecided (e.g. Lord Hindlip has a flowering season of apparently short duration, American Mother a long one in part due to very early opening of the terminal flower of the inflorescence). In the opening of the flower buds of the individual inflorescence of the apple the terminal flower characteristically expands first.

(b) *Inflorescence Form.*—The pose and compactness of arrangement of the flowers are characters of value dependent upon the number and size of the flowers, the pose of the corolla (cupped or flat) and the length and pose of the pedicels. The pose of the young leaves relative to the flowers and to the cluster base is often characteristic, but ultimately changes in leaf disposition associated with the effects of shading or overcrowding of the spur leaves tend to make this character unreliable. The pedicel of the terminal flower is typically shorter and stouter than that of a lateral flower: early opening inflorescences frequently tend to produce shorter pedicels than the normal, very late opening inflorescences and those from terminal buds on long shoots tend to produce abnormally long ones. Points of occasional value are the colour and pubescence of the pedicel, the shape and size of the inflorescence. Previously little attention seems to have been directed to most of these noticeable features of inflorescence form.

II. VARIETAL CHARACTERISTICS OF THE FLOWER.

Certain features of the corolla, viz.: colour, size, pose and texture, are naturally visualized as characteristics of the flower as a whole.

(a) *Colour.*—Bunyard (2) points out that the colour of the petal is a particularly prominent and reliable character when the individual flower buds are about the size of a pea seed and the terminal flower is on the point of opening. In full flower colour is not nearly so reliable an index: there may be great differences between varieties, but seasonal conditions modify the colour very rapidly. In the later stages of flowering of a tree, a purple tinge enters into deeply coloured flowers, and a similar purpling becomes very marked in coloured flowers as a result of frost, hot sun or drying wind. In sustained dry sunny weather the colour rapidly fades: pale flowers soon become quite white, brilliantly coloured flowers pale purple-pink. Bud and flower colour vary somewhat in intensity from year to year and varieties may not always retain the same relative intensity of colour, but these seasonal differences are hardly sufficient to interfere with the general usefulness of the character.

(b) *Size, Pose and Texture of Corolla.*—Flowers tend to be smaller and the pedicels shorter on recently transplanted trees, old unpruned trees and probably under other conditions of enfeebled growth. In the expanded flower the pose of the petals (2) and overlapping of the petals are helpful: in some varieties the flower remains round-cupped until the fall of the petals (Beauty of Bath, Lady Sudeley, Gladstone); others have wide open flat-bottomed cups (Charles Ross, Newton Wonder); some are cupped at first and later become flat except where neighbouring flowers are crowded together (Newton Wonder, Bramley's Seedling); others again are flat or even reflexed almost from the time of opening (Lane's Prince Albert, James Grieve, American Mother, Lord Hindlip) and a few form flat-sided cups (Annie Elisabeth, Edward VII, St. Edmund's Russet) Flowers in which the petals do not overlap are generally found in flat flowered varieties or in those with wide open cups (Charles Ross) or with narrow petals (Worcester Pearmain). Varietal differences in the texture of the petals are often patent to the eye; they include differences in petal thickness, firmness and in rugosity of the surface (contrast Bramley's Seedling, Newton Wonder, Lord Derby).

(c) *Calyx*.—The size and shape of the sepals are usually well defined characters during flowering (2). Their pose affords striking contrasts between varieties but the character is rather variable, it alters with the stage of maturity of the flower; the sepals generally tend to be more recurved in the later stages, but in some varieties the withering of the apex of the sepals about the time of petal fall may give an incorrect impression of a short spreading calyx. As a rule the calyx characters are more clearly defined in the flower than in the fruit but they are not necessarily similar at both these stages.

(d) *Corolla*.—Certain characters have been previously considered. Shapes of the petals are as follows: (i) *oval*, broad, rounded at both ends (Annie Elisabeth, Beauty of Bath); (ii) *oval-cordate*, broad, rounded at the apex, cordate or notched at the base (Grenadier); (iii) *orbicular-cordate*, very broad, roundish, base cordate (Gladstone, Lord Derby); (iv) *ovate*, tapering to the apex, rounded and broadest at the base (Rival); (v) *sub-ovate*, tapering to the apex, broadest near the base but tapering to the claw (Allington Pippin, Cox's Orange Pippin); (vi) *obovate*, rounded and broadest near the apex, tapering to the base (Charles Ross, Newton Wonder); (vii) *attenuate-ovate*, a narrow petal, broadest near the base, tapering to the apex and claw (Worcester Pearmain). The apex of the petal is usually *rounded* or *retuse* (bluntly notched); in some varieties it is strongly curled upwards and inwards, i.e. *hooded* (e.g. Newton Wonder). Length and stoutness of the claw or petal stalk and the character of the margin are also distinctive. Hairiness of the petal is confined to the upper surface and is most noticeable on the claw, main veins and near the apex; it is not sufficiently distinctive to be utilized in differentiating varieties.

(e) *Stamens*.—The length and the pose of the stamens should usually be observed about the time of anther dehiscence. In certain varieties (e.g. Bramley's Seedling, Lane's Prince Albert) the stamens are very erect but slightly divergent at the tips, appearing similar in collective shape to the trumpet of a daffodil; this pose is described as *coroniform*. Other common poses which are self-explanatory include: upper half only of stamens spreading (Grenadier), stamens rather spreading (Beauty of Bath), very spreading (Rival, Worcester Pearmain). Minor points worth noting are stoutness of the filament, the difference in size of the anther before dehiscence (e.g. Early Victoria has a relatively large anther on a slender filament) and differences in pollen productivity at dehiscence (e.g.

Bramley's Seedling is frequently poor in pollen production). (See also Crane and Lawrence, 5.)

(f) *Styles.*—In most cases the styles are late in elongating and should be studied after anther dehiscence. Bunyard (2) describes and illustrates photographically the principal characters : style length relative to stamens, length of the style column, the pubescence of the column, the junction and the terminal styles. It is probable that the styles are always united to some extent and the author does not find the clear cut distinction of columnar styles and free styles defined by Bunyard ; the column in the various varieties shows gradation in length. The terminal flower of the inflorescence usually has a shorter and stouter style column and it may be strikingly different in this character from the lateral flowers (e.g. Gladstone, Lord Derby) : for this reason no account is taken of the style of the terminal flower in the subsequent descriptions.

In regard to the constancy of stylar characters within the variety, variability in length of the style column has been observed in several varieties. Adverse weather conditions sometimes interfere with the normal development of both stamens and styles : on occasion a delay in normal elongation of the style column may be so caused and it leads to the appearance of flowers with short style columns in a variety in which the long column is normal. The last flowers to open frequently possess abnormally long styles or style columns, particularly when climatic conditions are favourable to growth. But in a number of cases the cause of variability is not known at present and until a satisfactory explanation is forthcoming there is need for caution in using stylar characters in diagnosis. Varieties examined in which marked variability in length of the style column has been frequently observed are Cox's Orange Pippin, Ellison's Orange, Grenadier and Ribston Pippin : sometimes extremes of column length were found on the same tree, in other cases a short column was characteristic of the flowers of one tree and a long column of another comparable tree of the same variety. Differences in pubescence of the style column of flowers of the same variety may often be correlated with the length of the column : the longest column is least densely pubescent probably because the elongation of the column either carries the hairs apart or leaves the earlier formed pubescence in the neighbourhood of the stylar junction or at the base of the column (Ribston Pippin). Nevertheless in at least one variety (Blenheim Orange) considerable variation in the density of pubescence *at the style junction* has been found to occur in flowers from the same tree : in this particular variety the style column itself is glabrous.

III. VARIETAL CHARACTERISTICS OF THE FOLIAGE.

The leaves on the cluster bases produced from fertile fruit buds usually develop somewhat before those on the infertile foliar spurs ; at flowering time the leaves of the former are therefore more mature and frequently differ in a number of respects, e.g. shape, colour, pose, from those on the foliar spurs. For these reasons the leaves produced on the inflorescence axis only are considered and described. During the flowering period most of the leaves are expanding more or less rapidly and their characters are variable and in some respects unfixed. On this account the characters of the young leaves should be used in confirmation rather than as a primary means of effecting an identification.

Size of the leaf at this stage is of no value at all; it is likely to be an index of nutritional conditions and of growth factors rather than a varietal character. Such characters as the shape of the blade, rugosity and folding of the surface, serration of the margin are sufficiently uniform at an early stage to be utilized. The normal leaf surface character should be distinguished from the puckering or blistering of the young leaf due to frost damage (14), to which certain varieties (e.g. Lord Derby, Cox's Orange Pippin) seem to be particularly susceptible. Colour and glossiness of the young leaf is varietal, but both may be modified by local nutritional conditions and the stage of maturity attained by the leaf. As previously stated the pose of the leaves is distinctive, but it is affected by overcrowding, shading and also by the position of the developing bud: spur fruit buds growing out horizontally produce leaves of irregular pose, probably under the inter-influence of gravitation and light, and the pose of leaves from terminal fruit-buds may also be quite different from those of the spur-buds. Leaf pose is most reliable on erect cluster bases growing from freely exposed spurs on the upper side of the more horizontal branches.

DESCRIPTION OF VARIETIES.

In order to illustrate the application of the methods of identification described in the foregoing pages, a few well known commercial varieties selected from the Ministry of Agriculture's list of profitable apples (15) are described in tabular form (see Table I and Plates I and II). A number of other well known varieties are described in another paper (11). The descriptions include all the characters which have been found of value in the recognition of varieties; in order to admit of ready extension of the list and to facilitate comparisons between varieties, the descriptions are made uniform even to the inclusion of characters seemingly unimportant to the particular variety. The outstanding features by which alone the variety may frequently be identified are *italicized.* Special technical terms are explained under the appropriate headings in the preceding sections dealing with Characters used in Identification (see also Boyes (1) and Jackson (9)). In the case of the foliage characters, it should be realized that the characters described are those of the young leaves on the flowering spurs, and it does not necessarily follow that they will bear any obvious

Table I.

Describing the Inflorescence Characters of Selected Com

	Bramley's Seedling. (Plate I, 2.)	Cox's Orange Pippin. (Plate II, 6.)	Early Victoria. (Plate I, 1.)	Grenadier. (Plate I, 3.)	James Grieve. (Plate II, 10.)
Flowering Season.	mid-season.	mid-season.	early-mid.	mid-season.	*early-mid.*
Inflorescence.					
Size, no. of flowers	medium, 6-7.	medium, 5-7.	*rather small*, 6-7.	*small*, about 6.	*rather small*, 5-7.
pose	*very crowded and stiff.*	*rather open.*	*crowded in bud, then rather compact.*	*crowded in bud and flower.*	*rather open erect in bud, then crowded and overlapping.*
Pedicel	*very short, very stout.*	medium to *long*, rather slender.	medium to rather short, stout.	medium *short*, stout.	*rather long*, medium slender.
pubescence	rather dense.	somewhat pubescent.	dense.	rather dense.	slight but prominent.
colour	pale green, faintly bronzed.	tinged purple.	pale whitish green.	plate whitish green.	bronzed grey green.
pose	erect, hidden by flowers.	erect-spreading.	*erect.*	*erect*, hidden by leaves.	erect.
Flower Bud.					
size, shape	*very large, very blunt*, margin of petal curves out.	medium, pointed ovate.	small, smooth, rather narrow.	small, short, corrugated.	small, smooth, pointed.
colour	*dark crimson lake striped.*	medium crimson to *crimson pink.*	carmine crimson, then *bright crimson pink.*	crimson *then pink.*	*deep bright crimson.*
Calyx.					
size, shape	*very large*, broadly acuminate.	*very long*, narrow.	*rather large*, triangular, acute.	*large*, long, acute.	*long*, narrow, tapering.
pubescence	rather dense.	somewhat pubescent.	very dense.	rather dense.	slightly pubescent.
pose	*spreading* or somewhat reflexed tip.	*rather laxly recurved against stem.*	*spreading or rather laxly reflexed.*	*laxly reflexed downwards*, tip recurved against stem.	spreading or reflexed, tip wavy touching stem.
Corolla.					
size	large.	medium large.	*small medium.*	medium.	medium.
pose and overlap of petals	*well cupped then nearly flat*, petals touching or overlapping.	*wide open cupped or flattish*, petals mostly touching.	cupped *then nearly flat*, touching or apart.	*wide open cup, much overlapping.*	soon *very flat or reflexed, petals apart.*
colour	*brightly suffused crimson.*	medium pink, fading.	bright pink, fades.	suffused pink.	crimson to pink, fades.
texture	*thick, rigid, smooth*	*rather thin*, faintly crumpled at first.	*rather thin, firm, smooth.*	rather thin, *much crumpled at first.*	medium, firm, *smooth.*
Petal shape	orbicular cordate to broad ovate.	ovate to sub-ovate, broad.	obovate to oval.	oval cordate, *broad.*	ovate to obovate.
base	*cordate or rounded with lateral folds.*	rounded, slightly tapering or rarely cordate.	*slightly tapering.*	*slightly cordate.*	usually tapering or with lateral folds.
claw	rather short, stout.	medium long, abrupt.	rather long, rather narrow.	appears short, broad, abrupt.	rather long, abrupt.
apex	rounded, retuse or slightly crenate.	rounded or retuse.	rounded, rarely slightly retuse.	rounded or retuse, *upturned.*	rounded or retuse.
upper surface	concave then flat.	concave then flattish.	*concave* then flat.	irregularly concave.	flat or slightly concave.
margin	sub-entire.	very faintly wavy.	*entire, upturned.*	irregularly wavy then sub-entire.	*entire.*
Stamens.					
length, stoutness	long, *stout.*	medium long, slender.	rather short, slender.	*short at first*, slender.	*short*, slender.
pose	*very coroniform.*	sub-erect.	sub-erect.	somewhat spreading in upper half.	sub-erect.
Styles.					
length relative to stamens	equal or slightly longer.	*usually longer.*	equal.	*equal or longer.*	*longer.*
style column	usually *very short*, stout.	*long, slender.*	rather short, slender.	short or long.	*short.*
pubescence	*very pubescent, particularly the broad junction* and coherent styles.	slightly pubescent junction.	junction pubescent, other parts sub-glabrous.	pubescent junction only.	pubescent junction only.
Foliage (Spur).					
shape	ovate, *broad*, thick, *stiff.*	ovate to oval, rather narrow.	ovate.	oval, rather long, *fleshy*, brittle.	ovate, *rather long*, thin.
colour, *shininess*	*dark green, very shiny.*	yellow green with *silvery pubescence, then very dark green,* shiny.	*yellow green, dull.*	*shiny dark green.*	*very shiny dark green.*
upper surface	*much cupped or rolled*, rugose.	upfolded, rather rugose.	*usually cupped*, slightly rugose.	*cupped*, somewhat rugose.	slightly upfolded, *very smooth.*
margin	large coarse acute serrate.	rather large creno-serrate.	small, shallow creno-serrate.	creno-serrate.	*wavy or twisted*, large, creno-serrate.
apex	abruptly acuminate.	often long, *slightly twisted.*	obtuse.	nearly obsolete.	prominent, gradually acuminate.
pose	*stiffly sloping outwards*, often held downwards.	horizontal closely surrounding buds, then slightly sloping outwards.	*horizontal close to flowers.*	horizontal just below flowers, then held down.	*laxly drooping* just below flowers.
Petiole	rather long, stout.	rather long, erect.	short, erect.	short.	rather long, laxly curved.

Note.—The characters *italicised* are the more outstanding features, by w *nercial Varieties of Apple.*

Lane's Prince Albert. (Plate I, 4.)	Lord Derby. (Plate I, 5.)	Newton Wonder. (Plate II, 7.)	Rival. (Plate II, 9.)	Worcester Pearmain. (Plate II, 8.)
mid-season.	mid-late.	*late.*	late-mid.	mid-season.
large, 6-8.	medium, 5-7.	*small for size of flower*, 5-6.	large, 5-7.	rather small, 4-6.
open, very wide spread.	*very crowded cluster on top of the leaves.*	*crowded, bunched overlapping.*	*rather compact at first, regular well spread.*	*very open*, erect spreading.
long, slender.	*very short, very stout.*	usually short, rather stout.	*short at first*, rather slender.	*very long, slender.*
dense.	very dense.	dense.	very dense.	sparse.
whitish green, slightly bronzed.	whitish green	pale green, some reddish.	pale green, faint bronze.	often purpled.
erect-spreading, then spreading.	crowded erect.	erect.	becoming wide spread.	erect-spreading.
rather small, oval.	short, *corrugated, coarse texture.*	*very large, round.*	medium, obovate, smooth.	medium, long obovate, very smooth.
very dark, brilliant carmine, becoming crimson.	*very deep red crimson.*	*pink or pale pink.*	*dull pink.*	*very dull* greenish pink veined mauve.
small, short acuminate.	large, rather broad.	*large*, long, *leafy.*	small, rather narrow.	rather small, *narrow*, very pointed.
very dense.	dense.	dense.	very dense.	sparse.
symmetrically *folded right back on calyx tube.*	spreading then tip reflexed to touch stem.	spreading or recurved against ovary.	obliquely *folded right back on calyx tube.*	*stiffly spreading* then tip recurved.
medium large.	large.	large.	large.	medium.
flat with concave margin, touching or a little apart.	well cupped, *much overlapping.*	*flat bottomed cup*, then flattish, *overlapping.*	*well cupped, open wide, mostly touching.*	*well cupped, open wide, petals far apart.*
bright crimson pink, striped white.	*brilliant dark red crimson.*	*very pale pink* to white, veined pink.	pale mauve pink, *soon whitish.*	*creamy white* veined pale mauve.
thin, *firm*, nearly smooth.	thick, *coarse texture and crumpled* almost bullate.	*rather thin*, crumpled at first.	medium, thick, firm, *very smooth.*	medium thick, *firm, very smooth.*
ovate to obovate.	orbicular cordate, some ovate.	broadly obovate, appears long at first.	ovate to oval.	*attenuate ovate*, some obovate.
usually tapering.	*cordate or rounded.*	gradually tapering.	slightly tapering.	much tapering.
longish, medium broad.	rather short, broad, abrupt.	appears long.	*long, slender.*	*very long, slender.*
rounded, *upturned at first.*	rounded, *much curled upwards at first.*	*very hooded and wavy.*	rounded, *upturned or slightly hooded.*	rounded, *hooded.*
slightly concave.	variable.	concave at margin.	*very concave.*	*very concave.*
entire, upturned.	*irregularly deeply rimmed, waved* or crenate.	*frilled and distinctly wavy, upturned.*	*entire, rimmed.*	*entire, rimmed.*
ong, slender.	*rather short* and stout.	*short.*	*very long*, rather slender.	*very long*, slender.
oroniform.	*sub-coroniform, then little spreading at top.*	sub-erect.	*very spreading.*	*very spreading.*
nuch longer.	equal or longer.	*longer or much longer.*	*shorter.*	equal or slightly shorter.
ery long, rather slender.	medium long, slender.	longish, stout.	mostly very short.	medium long and stout.
unction only very pubescent, usually scattered hairs elsewhere.	*very dense pubescence* at swollen *junction*, only slight below.	*column and junction densely pubescent.*	*junction and neighbouring parts very pubescent.*	somewhat pubescent to half way up styles.
vate.	ovate, long, thick.	ovate or obovate, *very broad, roundish.*	ovate to obovate, rather long.	mostly ovate, *narrow.*
ronzed yellow-green, dull.	*very silvery pubescent* then shiny dark green.	bright pale green, slightly shiny.	yellow-green to grey green, dull.	grey green, *dull.*
lightly upfolded or cupped, slightly rugose or smooth.	much upfolded, curled and coarsely waved, *often bullate, later smooth.*	irregularly cupped, rugose.	slightly upfolded, slightly rugose.	slightly upfolded or twisted, rugose.
ery shallow, creno-serrate.	usually shallow serrate.	*irregularly undulating*, very large teeth.	shallow crenate.	very shallow serrate.
hort, not prominent.	not prominent.	twisted.	not prominent.	often long, pointed.
orizontal or sloping outwards right down in full flower.	*stiffly held outwards* or downwards *just below flowers.*	horizontal or slightly sloping outwards *close to flowers.*	slightly sloping outwards below flowers.	rather erect then curved away from flowers.
hort.	rather long.	rather short.	rather short.	rather short.

ich the variety may be recognized.

relation to the characters of the mature foliage seen later on in the season. It may be stated that the adequacy of the varietal descriptions has been tested through their successful utilization by comparatively inexperienced students.

SUMMARY.

The description of the characters of the inflorescence of apple varieties has been comparatively neglected in works on systematic pomology ; the inflorescence forms a ready means of distinguishing varieties of apple during the flowering season.

The range of form of the various organs of the inflorescence is described : the constancy of each character and its relative value as a means of differentiating between varieties are discussed.

In order to illustrate the application of these methods of identification, ten well-known English varieties of apple are selected and their inflorescences are uniformly described in detail with the salient features italicized.

The author has pleasure in expressing his thanks to Mr. R. G. Hatton, the Director of the East Malling Research Station and to Mr. J. Bond, Head Gardener to Mr. J. H. Louden, Olantigh Towers, Wye, for facilities to examine trees of numerous varieties.

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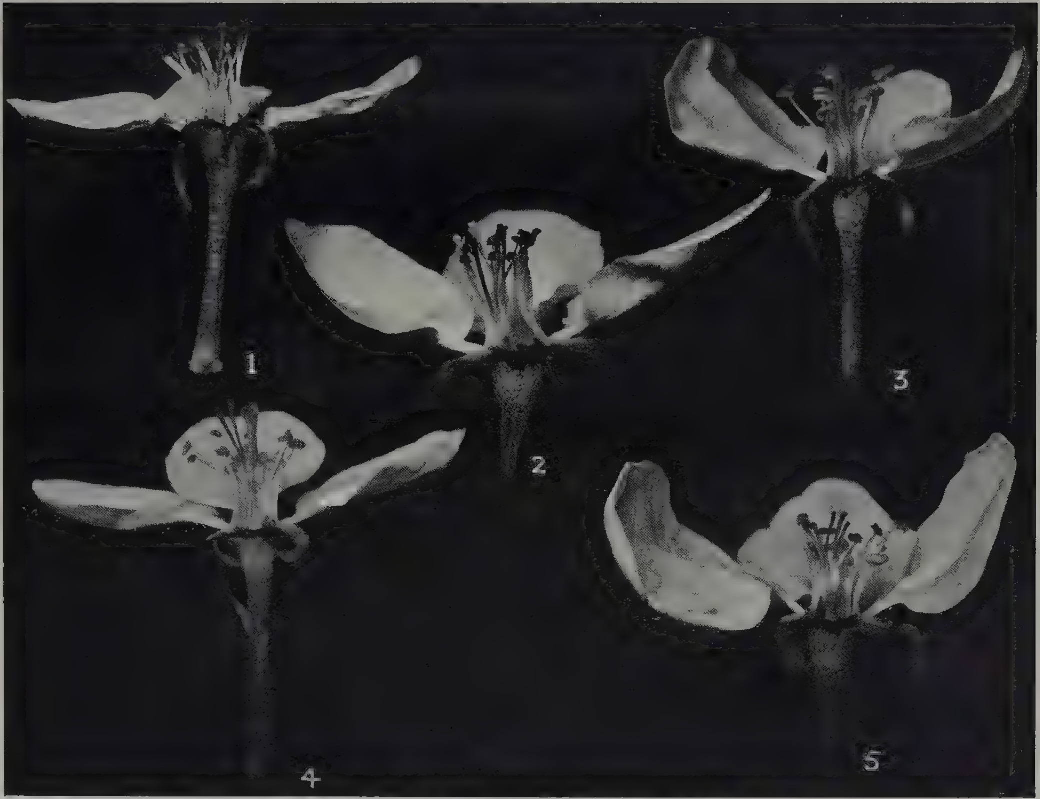
(*Received* 3/1/32.)

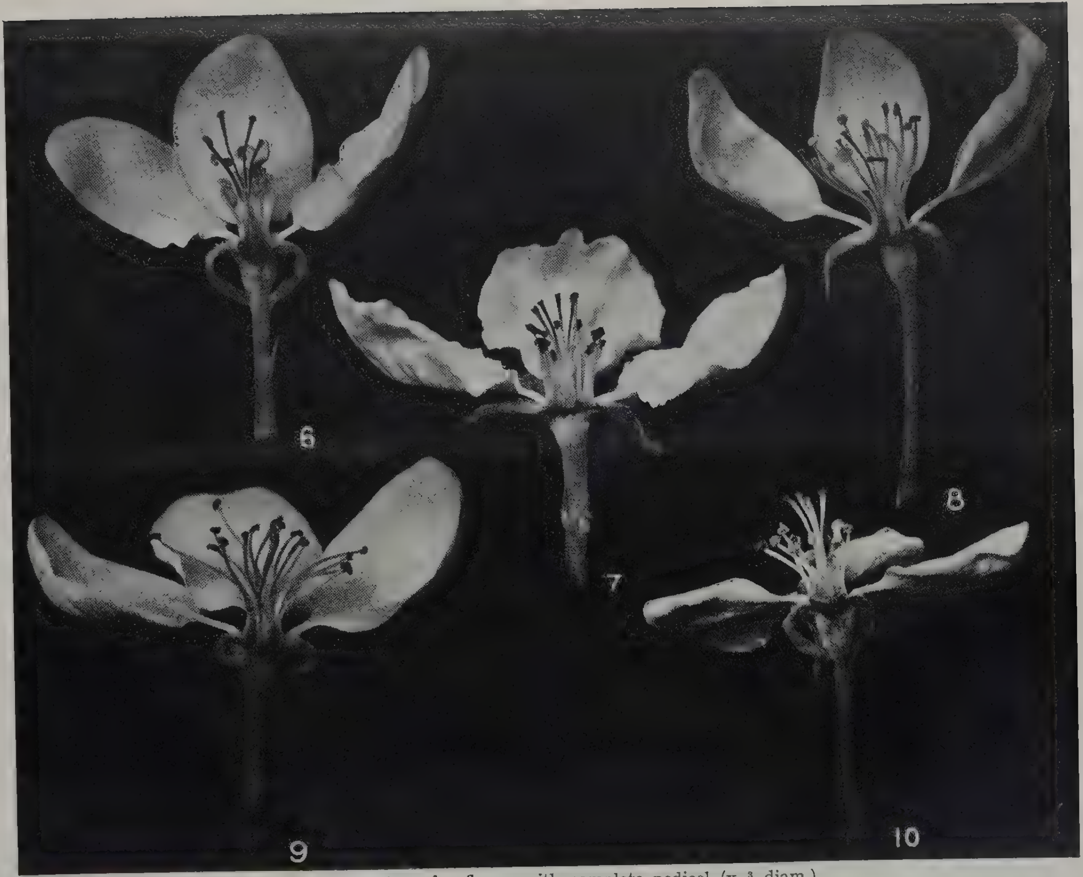
PLATE I.



Vertical section of a flower with complete pedicel (x $\frac{3}{2}$ diam.).

1. Early Victoria.
2. Bramley's Seedling.
3. Grenadier.
4. Lane's Prince Albert.
5. Lord Derby.

PLATE II.



Vertical section of a flower with complete pedicel (x $\frac{3}{2}$ diam.).

6. Cox's Orange Pippin.
7. Newton Wonder.
8. Worcester Pearmain.
9. Rival.
10. James Grieve.

EXPERIMENTS ON THE STORAGE OF PEARS IN ARTIFICIAL ATMOSPHERES.

II. SUBNORMAL OXYGEN ATMOSPHERES WITH AND WITHOUT THE ADDITION OF CARBON DIOXIDE.

By S. A. TROUT,

Australian Commonwealth Council of Scientific and Industrial Research, and the Low Temperature Research Station, Cambridge.

As a development of the investigation described in a previous paper (1) dealing with the effects of the exclusion of oxygen upon the ripening of pears, a series of experiments has been carried out in order to survey the effects upon the ripening and upon the respiratory metabolism of pears, firstly, of a series of atmospheres containing subnormal amounts of oxygen, and secondly, of the same series of low oxygen concentrations plus different amounts of carbon dioxide. Observations were made upon ripening as judged by colour, consistency, juiciness and taste, and upon the amount of anaerobic splitting of sugar to alcohol and carbon dioxide as judged by determinations of the alcohol- and acetaldehyde-content of the fruit.

Experimental Results.

The variety of pear used was Doyenne du Comice, a high-class dessert fruit, which was placed in gas-tight metal cabinets two days after picking. At this time the fruit was very hard, dark green and quite inedible. Each cabinet was provided with an inlet and outlet tube and held twelve trays, each containing twenty-five fruits. The experiment was conducted at a constant temperature of 3° C. and the following atmospheres were employed.

No. of Cabinet.	Oxygen per cent.	
1	21·0 (Air)	+ No carbon dioxide.
2	6·0	
3	2·0	
4	0·2 (Nitrogen)	
5	11·0	+ 10% carbon dioxide.
6	6·0	
7	2·0	
8	0·2	
9	6·0	+ 15% carbon dioxide.
10	2·0	
11	0·2	
12	2·0	+ 20% carbon dioxide.

These atmospheres, with the exception of the nitrogen and the air, which were supplied directly to the cabinets from cylinders, were made up in ten gasometers of approximately 60 cubit feet capacity. The gases were passed through the cabinets at such a rate that there was no appreciable difference between the composition of the storage atmosphere entering and leaving the cabinets. An analysis of the gas contained in each nitrogen cylinder used was made before the cylinder was connected to the cabinet, so as to ensure the use of gas free from all but traces of oxygen. Frequent analyses of the atmospheres within the cabinets were made. Three typical sets of results are shown in Table I in order to indicate the degree of accuracy obtained in gas control.

TABLE I.

Showing Gas Concentrations in the Cabinets. Three Representative Sets of Analyses.

No. of Cabinet.	CO_2 %	O_2 %	CO_2 %	O_2 %	CO_2 %	O_2 %
1	0·2	20·7	0·2	20·7	0·2	20·7
2	0·2	6·1	0·2	5·9	0·2	6·2
3	0·2	2·2	0·2	2·0	0·2	2·1
4	0·2	0·2	0·2	0·2	0·2	0·2
5	9·8	10·7	10·0	10·8	9·8	10·9
6	9·8	6·1	9·9	5·9	9·7	6·2
7	9·9	2·1	9·7	2·2	9·8	2·0
8	9·9	0·2	9·7	0·2	9·8	0·2
9	14·9	5·9	14·7	6·2	14·9	6·1
10	14·7	2·2	14·8	2·1	15·0	2·2
11	14·8	0·2	14·8	0·2	14·7	0·2
12	19·8	2·2	19·9	2·1	19·8	1·9

The cabinets were opened, and the stored fruit examined at the end of 21, 42, 56, 70 and 84 days. At each examination two trays were removed from each cabinet, and the fruit was allowed to ripen in air. The first batch of fruit was removed to 18° C., but this temperature proved to be too high for normal ripening, and consequently fruit removed at the end of 42, 56 and 70 days was placed at 10° C. Fruit stored in the artificial atmospheres for 84 days was divided into two lots, one of which was allowed to ripen in air at 10° C., and the other in air at 3° C. This latter temperature was selected in order to obtain results unaffected by temperature changes.

Control samples of fruit were also stored in air in ordinary storage chambers at 18° C., 10° C. and 3° C. on the day on which the experiment was commenced. The fruit placed at 18° C. was hard, ripe and very yellow at the end of sixteen days, but further storage at this temperature produced no softening, or breaking down of the cell wall, such as usually occurs in normally ripening fruit. Fruit placed at 10° C. ripened after twenty-five days and was of excellent flavour, yellow, soft and juicy; whilst fruit stored at 3° C. ripened after 120 days, but had lost some of its flavour. These results are summarized below.

	Temperature.	Time to ripen, in days.
Controls.	18° C. 10° C. 3° C.	16 25 120

The results obtained with the gas-stored fruit as regards time taken to ripen are summarized in Table II. The analytical results with regard to the formation of alcohol and acetaldehyde are given in Table III.

TABLE II.

Storage conditions.	Days to ripen in air at 10° C. after storage in various atmospheres at 3° C. for					Days to ripen in air at 3° C. after storage in various atmospheres for
	0 days	42 days	56 days	70 days	84 days	84 days
(No carbon dioxide)						
21·0% oxygen (Air)	25	21	10	10	8	36
6·0% oxygen		23	12	12	10	36
2·0% oxygen		25	12	12	10	40
0·2% oxygen		44	33	28	24	76
(10% carbon dioxide)						
11·0% oxygen		37	27	23	18	64
6·0% oxygen		37	29	25	20	64
2·0% oxygen		40	31	27	22	76
0·2% oxygen		44	36	30	24	76
(15% carbon dioxide)						
6·0% oxygen		44	33	30	22	92
2·0% oxygen		44	33	30	24	96
0·2% oxygen		46	36	30	24	96
(20% carbon dioxide)						
2·0% oxygen		47	40	34	27	96

DISCUSSION OF RESULTS.—(1) THE INFLUENCE OF SUBNORMAL OXYGEN.

At 3° C. the effect of reducing the oxygen concentration of the atmosphere upon the ripening changes is to retard them only very slightly, even when the content of oxygen is reduced to as low a value as 2 per cent. The alcohol- and acetaldehyde-determinations indicate that even with only 2 per cent oxygen present in the atmosphere at 3° C. there is an excess of oxygen, that is to say, we are still in the region above the extinction point of the anaerobic processes (2). From respiration results, (3), (4), (5), (6), (7), it may be assumed that the slight retardation observed in the presence of 6 per cent and 2 per cent

TABLE III.

Storage conditions.		Acetaldehyde in mgs./100 gms. of tissue. Number of days in storage at 3° C.				
		21	42	56	70	84
21·0% O_2	+0% CO_2	0·6	0·6	0·6	0·7	0·7
6·0% O_2		0·6	0·6	0·6	0·7	0·7
2·0% O_2		0·6	0·6	0·6	0·7	0·7
0·2% O_2		0·8	1·0	1·3	1·6	1·9
11·0% O_2	+10% CO_2	0·6	0·6	0·6	0·6	0·7
6·0% O_2		0·6	0·6	0·6	0·6	0·6
2·0% O_2		0·6	0·6	0·6	0·6	0·6
0·2% O_2		0·8	1·1	1·2	1·4	1·8
6·0% O_2	+15% CO_2	0·6	0·6	0·6	0·6	0·6
2·0% O_2		0·6	0·6	0·6	0·6	0·6
0·2% O_2		0·8	1·0	1·3	1·5	1·8
2·0% O_2	+20% CO_2	0·6	0·6	0·6	0·6	0·6
		Ethyl Alcohol in mgs./100 gms. of tissue.				
21·0% O_2	+0% CO_2	10·2	10·2	10·2	11·2	11·2
6·0% O_2		10·1	10·1	10·5	10·5	10·8
2·0% O_2		9·8	9·8	10·4	10·8	10·8
0·2% O_2		88·7	142·0	170·3	196·3	220·2
11·0% O_2	+10% CO_2	10·1	10·1	10·2	10·2	10·4
6·0% O_2		10·2	10·2	10·5	10·7	10·7
2·0% O_2		10·3	10·3	10·7	10·7	10·7
0·2% O_2		80·2	135·3	164·2	187·2	210·4
6·0% O_2	+15% CO_2	10·4	10·6	10·8	10·8	10·8
2·0% O_2		9·9	10·1	10·2	10·4	10·4
0·2% O_2		76·2	129·2	157·1	183·2	207·3
2·0+ O_2	+20% CO_2	10·4	10·4	10·6	10·6	10·6

oxygen as compared with 21 per cent oxygen (air), is associated with a corresponding small depression in the rate of CO_2-production.

There is another effect of oxygen concentration, besides that upon the ripening changes of yellowing, softening and flavour development, namely the effect upon what is described as sweetness. This effect clearly cannot be adequately discussed in the absence of acid and sugar determinations. The fact is recorded, however, that as the oxygen content of the storage atmosphere is reduced, the fruit, while otherwise ripening normally, develops less sweetness, and there seems little doubt but that this fact must be related to a difference in the ratio of sugars and acid present in ripe fruit. Kidd and West (6), working with apples, have noted that cane sugar is lost by hydrolysis more rapidly in an atmosphere containing 10 per cent oxygen than in air, but the rate of acid loss was not affected.

We have next to consider the results obtained in the present investigation in the case in which the oxygen content of the atmosphere was reduced to 0·2 per cent approximately. In this case we are clearly below the extinction point of anaerobic CO_2-production, for alcohol accumulates. The rate of alcohol accumulation, however, falls off with time, as the following table shows.

	Rate of accumulation (mgs. per day)	
	of Alcohol.	and of Acetaldehyde in 100 gms. of tissue.
1st period, 21 days	3·7	0·0095
2nd period, 21 days	2·5	0·01429
3rd period, 14 days	2·5	0·0095
4th period, 14 days	1·9	0·01429
5th period, 14 days	1·1	0·02859

Acetaldehyde also accumulates in the tissues, but this accumulation is very slight in comparison with that of alcohol.

The effects upon ripening obtained with a 0·2 per cent concentration of oxygen, i.e. below the extinction point of anaerobic CO_2-production, are in contrast to those obtained with subnormal oxygen concentrations above the extinction point. In the latter case, as has been seen above, we appear to be dealing simply with a retardation. In the former case, exposure to the artificial atmospheres produces not only retardation but also a definite change in capacity to ripen after removal. For example, the controls ripened in air at 10° C. in twenty-five days, whereas similar fruit after an exposure of forty-two days to 0·2 per cent oxygen at 3° C. subsequently took a further forty-four days to ripen in air at 10° C. This is the effect originally noted by Kidd and West (8).

It is interesting to note that in previous experiments by the author (Trout, 1) with Conference pears, which were already beginning to yellow and soften, exposure to nitrogen produced a retardation of ripening while in the gas, but no very marked effect of diminished capacity to ripen subsequently. It is suggested therefore that the occurrence of this after-effect must depend upon the stage of maturity at which the fruit is exposed to nitrogen, and that it occurs only if the fruit is exposed early, i.e., before starch loss, yellowing and softening have become noticeable.

It may be stressed here that even such a prolonged exposure as eighty-four days at 3° C. to 0·2 per cent oxygen and the accumulation of alcohol to the extent of 0·22 grams per 100 grams of tissue are well within the limits of the physiological tolerance of these pears.

(2) INFLUENCE OF CARBON DIOXIDE.

We come now to the results obtained in atmospheres of subnormal oxygen content when carbon dioxide in sub-lethal amounts is also present. The first fact that emerges is that the presence of carbon dioxide has no visible effect in these experiments upon the extinction point of anaerobic CO_2-production. Alcohol and acetaldehyde are found in 0·2 per cent oxygen, but not in 2 per cent oxygen, in all cases. Further, the rate and amount of formation is nearly the same whether carbon dioxide is present or not. Within the limits of these experiments, therefore, carbon dioxide has little depressant effect upon the process of anaerobic CO_2-production. As regards the effect of carbon dioxide upon the aerobic CO_2-production there is no direct evidence, but there is a clear and striking effect upon ripening, for instance, there is both a retardation while in the artificial atmospheres and a reduced capacity to ripen after removal.

Thus after eighty-four days at 3° C. pears, which had been stored in air and in atmospheres containing 6 per cent and 2 per cent oxygen, but no carbon dioxide, were yellowing and softening and took from eight to ten days to ripen on removal to air at 10° C. After the same period pears stored in atmospheres containing 6 per cent and 2 per cent oxygen, but with the addition of carbon dioxide (10 per cent and 15 per cent), were hard and green and took from twenty-two to twenty-four days to ripen on removal to air at 10° C., that is to say as long as the controls placed at 10° C. immediately after gathering. The after-effect of reduced ripening capacity is shown even more clearly in the case of shorter exposures. Thus :

(1) Twenty-five days taken to ripen in air at 10° C. immediately after gathering ;

(2) Twenty-three days taken to ripen in air at 10° C. after forty-two days at 3° C. in the presence of 6 per cent oxygen.

(3) Forty-four days taken to ripen in air at 10° C. after forty-two days at 3° C. in the presence of 6 per cent oxygen and 15 per cent carbon dioxide.

(4) Thirty-seven days taken to ripen in air at 10° C. after thirty-seven days in the presence of 6 per cent oxygen and 10 per cent carbon dioxide.

This is the first time definite values have been obtained which clearly demonstrate an after-effect of exposure to atmospheres containing sub-toxic amounts of carbon dioxide upon the rate of ripening of fruit. The effect has been noted in a general way in the case of apples kept by the " gas storage " process, which has been developed on the basis of the researches of Kidd and West. The fruit (Bramley's Seedling apples) on removal after five to six months' storage " stands up," to use a trade expression, and retains its green colour in a remarkable way during handling, packing and further storage in air during hot summer weather.

As regards the retarding effect of carbon dioxide during the period of exposure, the results of Kidd and West (l.c.) indicate that this is related to a reduced rate of carbohydrate loss by respiration, and the present results show clearly that this is not accompanied by any measure of anaerobic CO_2 production with alcohol formation. Whether or not the rate of carbohydrate loss remains depressed after removal to air is not known, nor is there any light yet as to what part of the respiratory mechanism is affected, or in what manner, by the concentration of carbon dioxide. For the moment, therefore, with regard to carbon dioxide we can do no more than note the effects.

With regard to the effect of the atmospheres containing carbon dioxide upon the flavour of ripened fruit, a definite change in the character of the flavour was noted. This change was easily detectable by certain palates, but not by others. For the purpose of description it has been denoted as "sickly." Such a flavour was invariably associated with the presence of carbon dioxide in the storage atmosphere, and its intensity was a function both of the time of exposure to carbon dioxide and of the concentration of this gas.

SUMMARY AND CONCLUSIONS.

The present communication is a contribution to the series of investigations at present being carried out by the Food Investigation Board with regard to possibilities inherent in the use of atmosphere control, as an adjunct to refrigeration, for the preservation of fresh fruits.

Attention has been given to the normal component gases of the atmosphere, nitrogen, oxygen and carbon dioxide. Of these, oxygen and carbon dioxide are physiologically important, while the nitrogen may be regarded as physiologically inert.

In the present paper the effects of subnormal amounts of oxygen in the air upon the storage life of Doyenne de Comice pears are described: and secondly the effect of various amounts of carbon dioxide in addition to subnormal concentrations of oxygen.

The pears were stored in the artificial atmospheres for periods up to eighty-four days at a temperature of 3° C. (37·4° F.). On removal from store they were ripened at 10° C. (50° F.) in air.

It was found that by lowering the amount of oxygen present during storage from 21 per cent (air value) to 2 per cent only a relatively slight retarding effect upon ripening and storage life occurred. The pears were normal and contained the usual quantities of alcohol or acetaldehyde.

With a further decrease of oxygen to 0·2 per cent a marked retardation of ripening occurred. After exposure the pears took longer to ripen at 10° C. in air, than did the control samples placed at 10° C. immediately after gathering. During exposure to this condition of low oxygen concentration the pears developed supernormal amounts of alcohol and acetaldehyde. They showed no visible injury either during exposure or during subsequent ripening in air at 10° C. It is probable that the after effect, i.e. the slower ripening after removal from low oxygen conditions of this order, does not occur unless the treatment is given while the fruit is still hard and green. In general the pears ripened after exposure to low oxygen conditions were less sweet than the untreated controls.

The effect of the addition of carbon dioxide in the case of all concentrations of oxygen above 2 per cent was the same. A marked retardation of ripening occurred and a pronounced after-effect of slower ripening in air. The after-effect in the case of carbon dioxide was not associated with the development of alcohol and acetaldehyde.

With 0·2 per cent oxygen the addition of carbon dioxide had little effect.

All the carbon dioxide treatments affected the flavour of the fruit, but no visible injury either external or internal was produced.

The present experimental survey shows conclusively that there are possibilities in the use of atmosphere control, as an adjunct to refrigeration, in the storage of pears. In view of the fact, however, that only one variety and only one temperature were studied and also of the fact that differences in flavour and sweetness were noted between the air-stored and gas-stored fruit, caution must be observed in drawing conclusions for practical application.

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(*Received* 1/2/32.)

GRAFTING AS A METHOD FOR INVESTIGATING A POSSIBLE VIRUS DISEASE OF THE STRAWBERRY.

By R. V. HARRIS,
East Malling Research Station, Kent.

I. Introduction.

In the late autumn of 1930 the attention of the writer was drawn to a serious deterioration disease of the strawberry prevalent in plantations and glasshouses in the Swanley strawberry growing district and present also on the trial plots at East Malling.* The resemblance of the symptoms of this disease to those of Strawberry Xanthosis or Yellows in America, as described by Plakidas (4, 5, 6), suggested that it might be primarily caused by a transmissible virus and it was therefore decided to investigate the disease from this point of view. This could clearly be done, in the first instance by the artificial infestation of normal plants with suspected insect vectors, or by methods of direct transmission such as grafting, leaf abrasion, etc. In experiments of the former description, however, the issue may be complicated by symptoms due to direct injury by the insect used. The alleged principal vector of Xanthosis in America, the aphis *Myzus fragaefolii* Ckll. is not recorded by Theobald in his most recent monograph (8) as occurring in Great Britain. But every plant examined by the writer showing symptoms of the disease, was also found to be infested with the strawberry Tarsonemid mite (*Tarsonemus fragariae* Zimm.), and in one instance also the aphis *Capitophorus fragariae* Theob. was identified on a group of diseased plants in the field. Now, both the aphis and the mite have been shown to produce severe symptoms of direct injury (1, 3). Those caused by mite infestation and described by Massee (3), although quite distinct from the symptoms of the disease under consideration were, in cases of severe attack, found to mask these symptoms. Briton-Jones and Staniland (1) in their account of the effects of Strawberry Aphis (*Capitophorus fragiariae*) on the Strawberry Plant, also state in a footnote that "Since the time of writing this paper a new disease of the strawberry has been described in California (4, 5). The disease there is known as 'Strawberry Yellows' and, as far as can be seen from the account and illustrations given, the symptoms are identical with those described in this paper. The disease is now accepted in California as being caused by a virus, probably carried by insects. An aphis (*Myzus fragaefolii*) is thought to be the principal vector."

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* The writer is indebted to Mr. W. Corbett, Advisory Officer in Glasshouse Work and Market Gardening for Kent, for drawing his attention to this disease, and for much subsequent assistance in initiating his experiments.

As the writer had previously used grafting methods of transmission with success in his study of raspberry virus disease (2) preliminary experiments were carried out in 1931 to determine the possibility of applying similar methods to the strawberry problem. These experiments gave positive results as to the possibility of grafting. They also provided evidence in support of the possible virus nature of the disease but, as they were designed primarily to test various methods of grafting, the number of comparable successful grafts in any one series was not sufficiently large to allow final conclusions to be drawn, and further experiments will be carried out using throughout the grafting method which has yielded the most satisfactory results.

The present communication describes briefly the methods of grafting tested, in the hope that they may be of use to investigators of similar problems in strawberry pathology.

II. GRAFTING EXPERIMENTS.

The variety said to be chiefly affected by the disease in Kent, and upon which the symptoms were first examined, was *Royal Sovereign*, and it was therefore decided to limit the preliminary experiments to this variety. The material used consisted of a number of specially selected apparently normal plants, potted in the autumn of 1929, and sets of diseased plants kindly collected and supplied by Mr. Corbett. A further series of plants showing analogous symptoms were also collected from the Research Station plots and potted.

All these plants were moved into a warm greenhouse in January, 1931. The normal batch of plants had remained free from insect infestation up to the time of the experiments, and were also apparently free from the Tarsonemid mite. They remained apparently free from mite until the middle of May, 1931, when they showed symptoms of infestation. All the diseased plants were, as already stated, mite infested. In spite of every effort to control this pest there was no doubt that the success of the grafting experiments was prejudiced by mite attack and, later, the symptoms of the disease under investigation, both on the original type plants and on the grafted runners, were obscured in varying degree for the same reason.

A. CLEFT-GRAFTING OF CROWNS.

Early in March an attempt was made to graft the crown of one plant directly on to another plant. The crown of the stock plant was exposed by removing from the pot a layer of soil about 2 cm. deep. The apex of the crown was then cut off and the remaining stem was cleft with a budding knife. The scion plant was then lifted, the roots and old leaves removed, and the stem cut into a wedge. This was inserted into the cleft in the stock crown, the graft bound with raffia and waxed, and the plant placed in a closed frame. The scion bud of plants thus grafted remained green for some weeks after grafting, and even in some cases commenced to develop, but eventually the stock root-system and crown rotted away in every case.

B. GRAFTING OF STOLONS.

Experiments on the grafting of stolons were made in May of the same year. Two types were attempted, cleft-grafting and inarching, and successful results were obtained with each. Throughout the following account of the methods employed the term *runner* is used in the sense adopted by growers and denotes the young plant (in all stages of developments from bud to rooted plant) developing on the creeping stem or *stolon*. The latter term is therefore used in contradistinction to *runner*, to denote the creeping stem itself, connecting a runner to its parent plant. In all the experiments to be described, only the primary terminal runners with their stolons have been used. Botanists use runner and stolon synonymously for the creeping shoot issuing from the parent plant. The term *scion-runner* refers to the runner which is to be removed (by severing the *scion-stolon*) from its parent or *scion-plant*, and grafted on to a stolon (the *stock-stolon*) issuing from the *stock-plant*. The corresponding runner from the latter is referred to as the *stock-runner*.

1. *Cleft-grafting* (Plate, Fig. 1).

The method used for this type of grafting was similar to that described by Roach (7) for the grafting of potato stolons, and was attempted at the suggestion of Mr. Roach to whom the author is also indebted for great assistance in making the grafts.

Runners in varying early stages of growth were used, from those the stolons of which were just growing out, i.e. had elongated about 10 cm., to those the primary leaves of which had just expanded. The best results were obtained at a stage between these extremes, i.e. with runners the stolons of which had completed their primary elongation and the leaves of which were just beginning to unfold (Plate, Fig. 1).

Two runners in a similar stage of development were selected. The stock-runner was severed from its stolon and discarded leaving the latter attached to the stock-plant. Two separate clove hitches of artificial silk (loosely tied) were then slipped over this runnerless stolon. The scion-runner was then cut off so as to leave about 2 cm. of stolon at its base, and this length of stolon, held flat along the index figure of the left hand, was cut into wedge form by two slicing cuts with a safety razor blade. The silk clove hitches having been slipped down out of the way, the stock-stolon was then cleft by a single cut with the razor-blade knife, the length of the cut corresponding to the length of the wedge on the scion-runner stolon. The latter was then introduced into the cleft, the clove hitches were slipped up over the graft (one to the upper and one to the lower end) and were tightened sufficiently to hold it firmly without constricting it. Finally the graft was coated with melted paraffin wax and the surplus silk ends cut off.

After grafting, the plants were kept in a humid atmosphere to prevent the wilting of the scion till union had taken place. It was not found necessary to put them in closed frames or other forms of damp chambers ; it was sufficient to place them on a moist ash bed, on an open bench in a low-pitched green-house with adequate shading. Of a total of twenty-eight grafts by this method three were entirely successful, the grafted runners being eventually rooted in pots. Several others commenced to grow out but subsequently died. In the three successful grafts the runners remained in a stationary condition for about a month after grafting, and then began to grow.

The very low percentage (8 per cent) of successful grafts by this method was undoubtedly due in the first place to faulty and unpractised manipulation. As in Roach's experiments with potato, the success of this form of grafting clearly depends on a perfect fit, clean cutting, and on the whole operation being carried through with extreme rapidity. There is no doubt, also, that the mite infestation previously mentioned affected the results very adversely, while finally it must be stated that in nineteen out of the twenty-eight grafts, either the scion or the stock plant was diseased.

2. *Inarching.*

By this mode of grafting it was found possible to graft a runner from one plant on to the stolon of another plant without completely detaching this runner from its parent plant till after union had taken place. Consequently no special precautions to reduce the transpiration of the grafted runner were necessary and the check given to its development was hardly appreciable.

Two methods were tried. In the first of these the runner from the stock-plant was discarded and its stolon was then grafted into the scion-stolon. After union had taken place the scion-stolon was severed leaving the scion-runner connected to the stock-plant. The second method differed from the first in that neither of the runners on the grafted stolons was removed. After union had taken place one of the stolons was severed, leaving one stolon bearing its own runner and an additional runner grafted on to it.

(a) *Method* 1 (Plate, Fig. 2). Two stolons, one from each of the plants to be inarched, with runners in a similar stage of development were selected. The runner from the stock-plant was then severed from its stolon and discarded, and the tip of this stolon was cut into a wedge about 1·5 cm. long by two slicing cuts with the razor-blade knife. An oblique cut was then made with this knife on the stolon of the scion-runner, either just below that runner or, as in the case illustrated in Plate, Fig. 2, about 8 cm. lower down. This cut was made starting towards the base of the stolon and working towards the runner, and was continued sufficiently deep just to avoid severing the vascular strand. The wedge-shaped tip of the stock-stolon was then inserted in the cut and the graft bound with raffia and waxed. Most of the grafted plants were placed on the bench in the greenhouse and no precautions to reduce the transpiration of the grafted runner were found to be necessary, as the vascular strand to this runner was not completely severed till the graft union was complete. From ten to fifteen days after grafting the graft was unbound and examined. If callusing was found to be satisfactory the scion-stolon was severed just beyond the graft thus leaving the scion-runner grafted to a stolon from the stock-plant. In no case must the original raffia binding be left in position after this period otherwise the stolon will become badly constricted in the region of the graft. Seven out of eight grafts attempted by this method were successful (i.e. the grafted runners were eventually rooted in pots), five of these consisting of normal runners grafted to diseased plants, and two, of normal runners grafted to normal plants. A successful graft is shown in Plate, Fig. 2. The stage of runner development at which the grafts were made varied from that giving the best results with cleft-grafting (Plate, Fig. 1), to the later stage at which the root initials of the developing runner were just visible.

This experiment also yielded results suggesting the transmission of a virus from the diseased plants to the normal runners grafted to them, but the number of comparable units was not sufficiently large for a final conclusion to be drawn. The results from this point of view were also badly masked by the mite infestation of the grafted runners already referred to. If, however, normal plants which are also mite-free are available for future experiments, it should be possible, after grafting by this method, to prevent the subsequent transit of mite from the diseased stock-plant to the normal runner by grease banding the stolon above the graft.

(b) *Method* 2 (Plate, Fig. 3 and Text Figs. 1 and 2). By this method neither of the runners on the grafted stolons was removed. The procedure was similar to that of Method 1 except that an oblique cut was also made in the stock-stolon running in the opposite direction to that made in the scion-stolon. Before making these cuts a thin slice of the epidermis and cortex the length of the proposed graft (about 2 cm.) was removed from each of the stolons (see Text, Fig. 1). The oblique cuts were then made and the tongues thus produced (see Text, Fig. 2), were engaged in one another, two cut surfaces of each runner (four in all) thus being brought into contact. Finally the graft was bound with raffia and the plants treated as by the previous method. After a lapse of from ten to fifteen days (by which time union had taken place) the stolon of the scion-runner was severed just beyond the graft leaving the stock-runner and the grafted scion-runner attached to the stock-plant by one stolon. All the grafts in this series were made with runners the root initials of which were just visible (i.e. the most advanced of the stages grafted by Method 1). Four out of the five grafts thus made were successful. In the fifth case the vascular strand of the stock-stolon was accidentally severed.

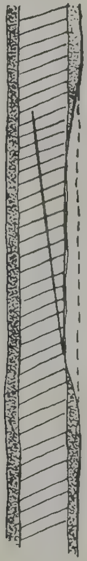

Fig. 1.

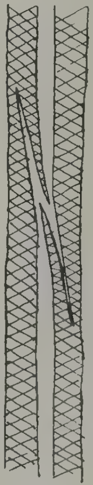

Fig. 2.

In conclusion the writer wishes to express particular indebtedness to Mr. W. Corbett for collecting material for the experiment and for much valuable information in the early stages of the work, to Mr. W. A. Roach and Mr. A. W. Witt for suggestions and assistance in making the grafts, to Mr. A. M. Massee for help in connection with the mite infestation, and to Mr. A. Tidy for his skilful care of the plants in the critical stages of the experiments.

SUMMARY.

1. An investigation of a disease of the strawberry similar to the " Yellows " or " Xanthosis " disease in America, as described by Plakidas, has been started at East Malling.

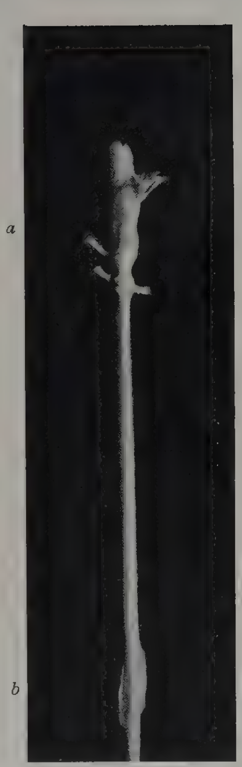

FIG. 1.

A "cleft-grafted" stolon, showing the stage at which the most successful grafts were made. (Natural size.)

a. Graft union, showing silk ties in position.
b. Vaseline band for mite trapping.

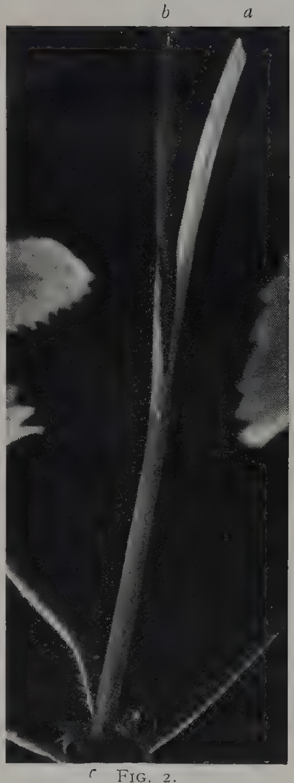

FIG. 2.

A successful graft by "inarching" (method 1). Photographed fourteen days after grafting. The scion-stolon has been severed and the raffia binding removed. (Natural size.)

a. Scion-stolon.
b. Stock-stolon.
c. Scion-runner.

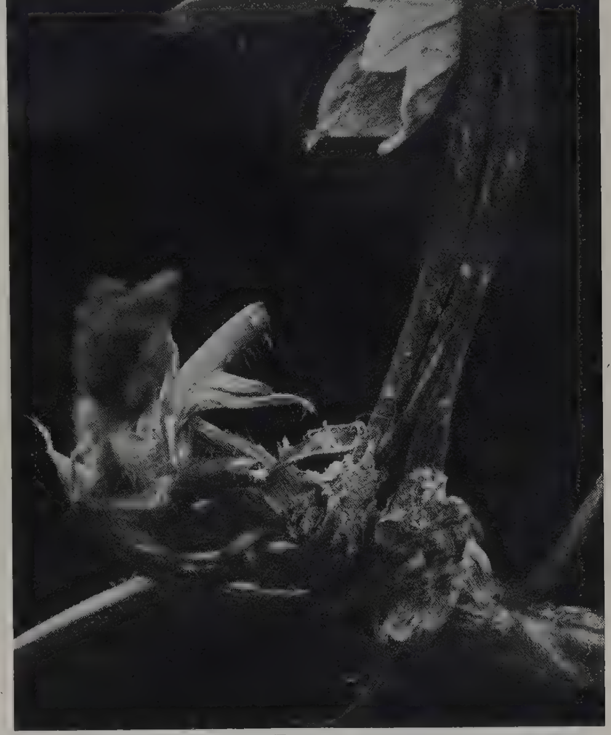

FIG. 3.

A successful graft by "inarching" (method 2). Photographed sixteen days after grafting (× 2). Note callus formation at union.

2. In order to obtain a method for determining the possible virus nature of this disease which would not involve the infestation of plants with suspected insect vectors, and thus introduce the masking factor of direct insect injury, experiments to determine the possibility of grafting strawberry plants were carried out using the variety *Royal Sovereign*.

3. Attempts to graft the main crowns of plants were unsuccessful.

4. Experiments in cleft-grafting and inarching the stolons of runners were successful and the methods used are described in detail.

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(*Received* 3/3/32.)

FACTORS GOVERNING FRUIT BUD FORMATION.

IX. A STUDY OF THE RELATION BETWEEN LEAF AREA AND INTERNODE LENGTH IN THE SHOOTS OF WORCESTER PEARMAIN APPLE, AS AFFECTED BY SIX DIFFERENT VEGETATIVE ROOTSTOCKS.

By THOMAS SWARBRICK and *K. C. NAIK,

Agricultural and Horticultural Research Station, Long Ashton, Bristol.

INTRODUCTION.

In a study of the leaf area of spurs on biennially bearing apple trees, Swarbrick (26) has shown a definite relationship to exist between leaf area and blossom bud formation in apples. The importance of the leaf in the matter of fruit bud formation is well known and may be instanced by the work of Roberts (22, 23, 24), Magness (18, 19) and Goff (8). Gourley (9) also found that a much larger leaf area was produced in the " off " year on alternate year bearing apple trees. Jones (17), in his studies with the Sugar Maple found that the capacity of trees to yield sugar in their sap varied from year to year in direct proportion to the previous years' leaf area. Harvey and Murneek (14) have shown that defoliation early in the year markedly decreases fruit bud formation. They point out that a close relationship exists between the number of leaves, the percentage of spurs setting fruit and the average weight of the fruit.

Valuable work has also been done in recent years in the direction of elucidating the relationship between tree growth and fruiting performance. Swarbrick (27), Roberts (22, 24), Dorsey and Knowlton (6) and others have shown that a definite relationship exists between the elongation growth of shoots and spurs, and their fruit bud formation. The aim of all such work is to discover the type of growth that is associated with the desired fruiting conditions and the growth modifications that may be induced by cultural practices.

It is well known that some rootstocks considerably modify the vegetative vigour and productivity of the scion. Vegetatively propagated rootstocks have also been shown to influence the precocity with which trees worked upon them come into bearing (11, 12). It is suggested that a more adequate knowledge of the varying morphological responses induced in a scion variety by these rootstocks and the relationship of these morphological features to the tree performance will have an important bearing on the cultural operations in fruit production.

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* Mr. K. C. Naik is a horticulturalist in the service of the Punjab Government, India, and has carried out this study during a study-leave period spent at Long Ashton. Mr. Naik has since returned to his normal duties in India.

In the present investigation, a study has been made of the leaf area and internode length of the apple "Worcester Pearmain" growing upon six different standardized vegetatively propagated rootstock, with a view to elucidating their relationship to fruit bud formation. This work should be considered as a detailed part of the programme in a general investigation into "The Factors Governing Fruit Bud Formation" proceeding at Long Ashton. Studies on fruit bud formation were initiated at Long Ashton by Barker and Lees in 1916 (1, 2) and have since then been developed along several lines by Summers (25) and Swarbrick (26, 27). The present study presents further data upon one other aspect of this general problem, namely, the relation between growth phenomena and flower bud formation as influenced by rootstocks in the apple variety Worcester Pearmain.

METHOD OF PROCEDURE AND MATERIAL EMPLOYED.

The "Apple Stock Trial Plot" at Long Ashton supplied the material for this investigation. This plot is composed of eight trees each of the apples Worcester Pearmain, Bramley's Seedling and Lane's Prince Albert, worked on to each of twelve standardized vegetatively raised rootstocks. The scion variety Worcester Pearmain is the only one used for the purpose of this investigation.

Trees growing upon six of the above twelve rootstocks were selected for this work and these are referred to by their accepted abbreviations, namely Malling I, IX, X, IV, XII and Bristol 5.

The plot was laid out in the winter of 1919-20, for supplementing the data accumulating from the extensive trials of so-called "Paradise" stocks initiated by Hatton at East Malling (11, 12).

The trees are standing on a fairly level piece of land with a satisfactory drainage. Every care has been taken to avoid differential treatment to the trees within the variety. The pruning has been standardized to a rule of thumb procedure and has been carried out as far as possible by the same operators. The trees are kept open-centred, leader tipping being done every year. Laterals over nine inches are spurred to about five good buds.

In the middle of October, 1930, after extension growth had ceased for the year, measurements were taken of the internode lengths and leaf areas of about thirty shoots on each of the eight trees on the six selected types of rootstock. In the case of rootstock M.IX and Bristol 5 there were only seven trees upon which measurements could be taken. The total number of shoots measured were as follows:—209, 239, 236, 185, 239, 214 for Bristol 5, Malling XII, X, IV, I and IX respectively.

The measurements in each case started at the previous year's leaf scar, and the length from this to every successive internode above was measured. From these measurements the total length of each shoot was obtained, its number of internodes and the length of each successive internode in order of development.

The measured shoots were then classified into groups according to the number of internodes per shoot. Thus classified, the three groups containing the largest number of shoots are considered in detail in this study since they probably represent the average shoot condition upon each stock type. In most cases the data of the largest group only is given in the tables.

The mean internode length and mean leaf area of each successive node in the shoots of these three largest groups was calculated. The measured shoots upon each of the rootstocks were all treated in this way.

In order to test the variability of the material and the reliability of the measurements probable error figures were extracted for the " mean leaf areas " and " mean internode lengths " of each successive node on the shoots where M.IV served as the rootstock. The probable error figures obtained were so small in relation to the size of the differences clearly involved, that similar figures were not extracted for the shoots upon the other five rootstocks.

The leaf area of each successive leaf upon each shoot was also obtained at the same time as the internode length. The leaf area was obtained by taking two measurements upon each leaf, namely the greatest length and the greatest width. A practical difficulty was sometimes involved in deciding the position of the maximum width of a leaf, but in most cases the point was not difficult to fix. Where leaves had been damaged the measurement was made so as to approximate as nearly as possible to the assumed shape and size of the leaf. The leaf areas and internode lengths were invariably taken from the base of the shoot upwards. In this way the measurements give the successive leaf areas and internode lengths in the order of their development.

In order to obtain an accurate measure of the " real " leaf area of the leaves, five typical shoots from each tree under investigation upon each rootstock were taken and the leaves removed in acropetal order. These leaves were marked and numbered and pressed in blotting paper. Length and breadth measurements of these leaves were then taken and the " theoretical " leaf area calculated. In this way a figure was obtained similar to that which would have been obtained in the field. These leaves were then placed on squared paper and outlined and from this the " real " leaf surface was obtained. The relation of this " real " to the " theoretical " leaf surface will be discussed later.

From the above series of observations and measurements the correlation coefficient between internode length and leaf area for each successive leaf and internode has been calculated. This is given in a subsequent section.

The trees used in this study form part of an important plot at Long Ashton and complete records of their blossoming, growth, and crop production are available. The trees are the same as those used by Swarbrick (27) in his study of " Factors Governing Fruit Bud Formation " reported in 1929. Furthermore, data upon the number of blossoms produced in the terminal, axillary, and spur positions have been collected upon these trees over many years. These data are used in conjunction with that obtained in the present study, in a discussion of the factors affecting fruit bud formation.

EXPERIMENTAL DATA AND OBSERVATIONS.

(1) *The effect of rootstocks upon the internode lengths of the shoots of Worcester Pearmain.*

Throughout the subsequent part of this paper the data given will often be that of the largest group of shoots only. In every case where data for the largest group of shoots is given similar calculations have been made for the second and third largest groups. In some cases the data for the whole shoot population which was measured has been calculated. Owing to lack of space for tabular matter the tables for the second and third largest groups cannot be given. In some cases reference will be made to these second and third largest groups although their data are not given. The conclusions drawn are always based upon a consideration of all these three groups of shoots, although since the data of only one of them is given, specific reference must be made to this group only.

Approximately two hundred shoots of Worcester Pearmain were measured growing upon each rootstock. When these were grouped upon a " number of internodes " basis, approximately 50 per cent of the shoots fall into the three largest groups in the case of rootstocks M.XII, M.X, M.IV and Bristol 5. In the rootstocks M.I and M.IX only 39 and 41 per cent respectively fall into the three largest groups.

Considering first the effect of rootstock upon the number of internodes per shoot in the largest group of shoots upon each rootstock, there is a difference of only three internodes. Thus, the largest group of shoots on the rootstock M.IX has 34 members with 18 internodes each, and the rootstock M.X has 48 members with 21 internodes each. In the second largest group the range due to rootstock influence is from 17 to 21 internodes and in the third largest group from 16 to 19 internodes. It is clear, therefore, that in the main shoot population of the trees upon these six rootstocks the number of internodes per shoot is surprisingly close, when the large difference in tree size is remembered.

The effect of rootstock upon internode length is shown in Table I. This table sets forth the mean internode length of each successive internode up the shoot for the largest group of shoots upon each rootstock. It also shows the number of shoots from which this mean was obtained, and their total length. The internode lengths are given in acropetal order so that a direct comparison is possible between any given set of internodes.

It is found that where M.IX is the rootstock there is a uniform mean internode length of 1·4 cms. in all three groups of shoots. In all other cases the length varies from 1·6 to 1·9 cms. In the largest group of shoots (Table I), for example, the average internode length for M.IX is 1·4 cms., whereas for all the others it is either 1·8 or 1·9 cms. It is clear that the rootstock M.IX induces shorter internodes than any other rootstock here under investigation. The remaining rootstocks can be grouped together since there is so little difference in their internode lengths.

TABLE I.

Showing the average internode length of each successive internode from the base of the shoot upwards.

Largest Group.

(In cms.)

Rootstock	B.5.	M.XII.	M.X.	M.IV.	M.I.	M.IX.
Total No. of shoots in the group .. .. .. and % of total shoots ..	39 19%	49 20%	48 20%	34 18%	35 15%	34 15%
Number of Internode from base of shoot :						
1	0·5	0·5	0·5	0·5	0·5	0·5
2	0·4	0·4	0·5	0·5	0·5	0·5
3	0·7	0·7	1·1	0·9	0·7	0·7
4	1·0	1·2	1·2	1·5	1·2	1·0
5	1·7	1·7	1·7	1·9	1·6	1·1
6	1·9	2·1	1·9	2·3	1·9	1·3
7	1·8	2·0	1·8	2·4	1·7	1·4
8	1·9	2·0	1·9	2·0	1·9	1·4
9	2·2	2·2	2·0	2·5	2·0	1·7
10	2·2	2·2	2·1	2·4	2·1	1·8
11	2·2	2·2	2·2	2·3	2·2	1·8
12	2·4	2·4	2·4	2·6	2·4	1·9
13	2·6	2·6	2·3	2·5	2·6	2·1
14	2·6	2·6	2·5	2·4	2·5	2·0
15	2·4	2·7	2·5	2·4	2·6	2·0
16	2·4	2·5	2·4	2·3	2·5	1·7
17	2·4	2·5	2·5	2·4	2·7	1·7
18	1·9	2·3	2·5	2·3	2·4	0·7
19	0·8	1·5	2·0	1·5	2·1	—
20	—	0·8	1·5	1·4	1·7	—
21	—	—	0·6	0·6	1·0	—
Total length of shoot ..	34·0	37·1	38·1	39·6	38·8	25·3
Average internode length	1·8	1·9	1·8	1·9	1·8	1·4

A more detailed examination of Table I reveals several interesting points of difference induced in the scion variety by the rootstocks. One such feature is the position and arrangement of the long and short internodes along the shoots where M.IV and M.IX serve as the rootstocks.

The current year's shoot may be divided into three parts according to the prevailing internode length. For example, where M.IV is the rootstock the shoot may be divided as follows:—

(1) From the 1st to the 5th internode from the base with internode lengths varying from 0·5 to 1·5 cms.

(2) From the 5th to 18th internode from the base with internode lengths varying from 1·9 to 2·6 cms.

(3) From the 19th internode onwards with an internode length varying between 1·5 and 0·5 cms.

The shoot, therefore, is clearly divided into three definite growth periods and the Sach's Grand period of growth is expressed very graphically in the prevailing internode lengths of each part of the shoot.

The mid portion of the shoot with the relatively long internodes—exceeding 2·0 cms.—starts at a *lower* node where M.IV serves as the rootstock. In the three largest groups here under review these longer internodes commence at the sixth or seventh internode where M.IV is the rootstock, while with the rootstocks M.I and Bristol 5 they commence uniformly at the ninth internode, a clear and consistent difference of two or three nodes. The influence of M.IV is also shown in the cessation period of the long internodes, for a marked decrease in internode length is apparent at the third to fourth internode from the tip of the shoot. In all the other cases this decrease occurs at the second or third internode from the tip. The rootstock M.IV is outstanding, therefore, in that it induces long internodes *early* in the growth period of the shoot but also in that it ceases to have long internodes relatively early.

In a comparison of M.IX with the other rootstocks here under investigation marked differences are found in both internode length and arrangement.. In the first place the long internodes—over 2·0 cms.—are confined to a narrow region of the shoot, usually covering not more than four internodes. These long internodes are found at about the tenth to the fifteenth internodes, that is, they occur *very late* in the growth period of these shoots, and are in contrast to their early appearance in the shoots upon M.IV. This lateness in the production of the long internodes is brought into even greater prominence when it is remembered that at most, the shoots on M.IX have only eighteen internodes. It is also shown in Table I that where M.IX is the rootstock the long internodes never exceed 2·1 cms. long, whereas in shoots where other rootstocks have been used, internode lengths of 2·5 cms. are very common and as much as 2·8 cms. has been recorded.

These differences in internode length and the distribution of the long internodes along a shoot, mark out the two rootstocks M.IV and M.IX. In the former the period of long internodes occurs early in the life history of the shoot, but it also closes early. In the case of M.IX the long internodes do not occur until late in the growth cycle of the shoot and they are few in number, rarely, if ever, more than five. This situation is in marked contrast to M.XII for example, where there are thirteen long internodes in the largest group of shoots.

This periodicity in the formation and number of long internodes is a morphological expression of an internal metabolism and has a distinct bearing upon the problem of blossom bud formation, particularly the terminal and lateral blossom production on one year wood. A discussion of this point will follow later.

A further point brought out in Table I is the fact that with all rootstocks the first four internodes are approximately of equal length and that in only one case does the length of the first four internodes exceed 1·0 cm. In fact, except for M.X rootstock, the internode lengths are very similar up to the fifth internode. The rootstock M.IX is outstanding in that its internodes, except the first four, are invariably shorter than the corresponding ones on any other rootstock. This, and the fact that these shoots do not have more than five long internodes, accounts for the very low average internode length, 1·4 cms. against 1·8 to 1·9 in all the other rootstocks.

The effect of rootstock upon internode length may, therefore, be briefly summarized as follows. Rootstocks influence total shoot growth so that the average shoots on M.IX are approximately 25·0 cms. long, whereas those on M.IV, M.I and M.X and Bristol 5 are 39·6, 38·8, 38·1 and 34·0 cms. long respectively. The number of internodes in these shoots does not vary so widely as the disparity in length might lead one to expect. There are eighteen internodes in the shoots of M.IX which are only 25·0 cms. long and only twenty-one in those of M.IV where the shoots are 39·6 cms. long. This fact is important, since it must be remembered that a leaf is attached to every node. M.IX has an average internode length of 1·4 cms., whereas the other rootstocks give an average of 1·8 and 1·9 cms., a clear difference of 0·4 cms. Differences in the distribution of the long internodes along the shoot are evident. In M.IV the long internodes occur very early in the life of the shoot, whereas in M.IX they occur very late. In the case of M.IX there are only four or five long internodes, whereas with the other rootstocks there are eight or nine and in some cases as many as thirteen. It is shown that rootstock does not affect the length of the first four internodes along a shoot. These are always less than 1·0 cm. long irrespective of the rootstock. These data bear upon the problem of flower bud formation, particularly on current year's shoots, and will be discussed in a later section.

(2) *The effect of rootstocks upon the size of leaves of selected shoots of Worcester Pearmain Apple.*

The effect of rootstocks upon the size of leaves was studied by obtaining the area of the leaves while still attached to the tree. This was done by taking the measurements of greatest length and greatest width. The measurements were taken at the same time as those of the internode lengths discussed in the last section. Each leaf was measured in acropetal order so as to give a developmental series.

According to the prevailing ideas upon the make up of the shoot system of the tree, the leaf and the part below it should be considered as comprising a physiological unit. In taking these records, the first internode above the leaf scars was measured and the leaf immediately above this internode was considered as belonging to it. In this study, therefore, the leaf and the internode immediately below are considered as a unit of construction and development.

It was noted above that for the measurement of leaf area two records were made, those of greatest length and greatest width. A " theoretical " leaf area is obtained by the multiplication of these two figures. Since the leaf is not square there is every reason to expect that there will be some difference between the " real " and " calculated " leaf areas. In order to discover this difference, its direction and magnitude, typical shoots were collected from the trees under investigation, growing upon each rootstock. The " theoretical " leaf area of each leaf was calculated as for the leaves in the field. The " real " leaf area of these same leaves was obtained by tracing their outline on to squared paper in a manner similar to that previously employed by Swarbrick (26). The leaves were measured in acropetal order and five shoots upon each rootstock were measured and compared in this way.

It is found that the greatest average difference between the " actual " and the " calculated " leaf area does not exceed 0·6 sq. cms. This occurs in the case of shoots with M.X and M.IV as rootstocks. In the case of Bristol 5 the average difference is only 0·087 and in M.XIII 0·159 sq. cms. In a total of 568 leaves compared, the " calculated " leaf area exceeds the " actual " by an average of 0·38 sq. cms. It is shown later in Table II that the lowest average leaf area per leaf is 33·16 sq. cms. and in view of this, the difference of 0·38 sq. cms. would appear to be less than the error introduced by the difficulties of accurate measurement in the field.

For all practical purposes, therefore, the " calculated " leaf area would appear to adequately represent the " real " leaf area in the case of Worcester Pearmain where a reasonable number of leaves are measured. This point in itself is extremely interesting and was not expected, since previous experience with other varieties had shown a definite ratio of less than unity to exist between the calculated and the actual leaf areas (26). This fact raises the whole question of varietal habit and leaf shape and, if the above observations are further substantiated, suggests that where leaf area studies are concerned, the variety Worcester Pearmain offers considerable advantage in that its " actual " and " calculated " leaf areas are for all practical purposes the same.

A further point of interest brought out by the study of the above differences is that the largest difference between the "actual" and the "calculated" leaf areas invariably occurs in the region between the seventh and the eighteenth internodes, i.e., in the region where the leaves are the largest and the internodes the longest. In any case the largest individual difference found between these two areas, viz., the "calculated" and the "real," was only 6·9 sq. cms. Since in this case the "calculated" leaf area was over 40·0 sq. cms., the error involved by assuming that the "real" area was obtained by the field measurements taken was 17 per cent. Clearly, in the nature of the case, errors due to the practical difficulties in measurement might easily produce errors of the above magnitude. The whole question of obtaining a rapid practical method for the measurement of the leaf area of growing leaves is one of great interest and importance, and requires further detailed study.

TABLE II.

Showing the relation between internode length and leaf area as expressed in the ratio leaf area and internode length.

Mean leaf areas and internode lengths of the largest groups for each stock.

No.	Stock.	Mean leaf area.	Mean Internode length.	Leaf area.
				Internode length.
1	B.5	33·16	1·8	18·4
2	M.XII.	34·95	1·9	18·0
3	M.X.	38·96	1·8	21·6
4	M.IV.	39·91	1·9	21·0
5	M.I.	41·13	1·8	22·9
6	M.IX.	37·22	1·4	26·6

The effect of rootstock upon the average leaf area of leaves at every successive internode has been studied and Table II sets forth in a convenient form the summarized data that has been obtained. It is seen from Table II that the rootstocks do influence average leaf size. The mean leaf areas for the rootstocks M.I, M.IV, M.X, M.IX, M.XII and Bristol 5, respectively, in order are 41, 39, 38, 37, 34 and 33 sq. cms. It is interesting to note that the size of the leaves is not directly related to the known vigour of shoot growth induced by rootstocks. Thus, the vigorous rootstocks M.XII and Bristol 5 have clearly the smallest leaves. Their average leaf size is so nearly alike and so far removed from the remainder as to put these two rootstocks into a distinct group. They give vigorous large trees but the shoots have relatively small leaves. M.IX stock is the third lowest in leaf size, but the difference in size of the leaves on this stock from those of stocks M.IV and M.X is not large. The difference from M.I, however, is quite appreciable. As regards leaf size, therefore, the rootstocks

M.I, M.XII and Bristol 5 are outstanding, the first because it induces large leaves, and the two latter because they induce small leaves.

The data on the effect of rootstock upon internode length have already been presented in a previous section, where it was shown that M.IX was outstanding because of its relatively short internodes. The effect of rootstocks upon the ratio of leaf area to internode length is also set forth in Table II. The ratio figure obtained by dividing mean leaf area by mean internode length employs both internode length and leaf area, and gives a direct index to the amount of leaf area which a unit length of shoot has upon it. This ratio clearly indicates that there are three classes of shoots. M.IX forms a class by itself with a ratio of 26·6. The second class is made up of M.I, M.X and M.IV with ratios of 22·9, 21·6 and 21·0 respectively. The shoots of M.XII and Bristol 5 are outstanding with ratios of 18·0 and 18·4 respectively. It is clear, therefore, that the rootstock M.IX, although it gives short shoots with a fewer number of leaves per shoot, yet because of its short internodes does give the largest leaf area per unit length of shoot. In the case of the vigorous rootstocks M.XII and Bristol 5 the leaves are small and the internodes long ; therefore the ratio is low. This means that by comparison with M.IX the leaves of the trees on M.XII must supply much more material for frame work building, so that in effect the axillary buds have much less leaf surface available to them as a source of carbohydrate supply.

The ratio of leaf area to internode length is undoubtedly an important consideration since it singles out at once the rootstocks M.IX, M.XII and Bristol 5. It will be shown later that this ratio figure is directly related to the precocity induced by these rootstocks. It is important, however, to point out that neither leaf size nor internode length taken alone give any direct indication of vigour or precocity. The *ratio* figure of leaf area to internode length more closely coincides with the known precocious tendencies in rootstocks. Of the rootstocks here under study this order would be M.IX, M.IV, M.I, M.X, M.XII and Bristol 5. This order corresponds very closely indeed with the ratio figures given in Table II. It would appear, therefore, that the ratio figure is a more reliable index to the fruitful condition in apple trees than either leaf size or internode length taken alone or studied side by side.

(3) *The effect of rootstock upon the leaf area of the "terminal rosette" of leaves.*

It has already been shown that rootstocks influence leaf size and internode length. Table III shows that they also affect the total leaf area of the terminal rosette of leaves. This terminal rosette is formed at the end of the growing period of the shoot by the failure of the internodes to lengthen. The condition, in fact, approaches to that of a typical fruit spur except that the number of leaves in the terminal rosette rarely exceeds three or four, whereas in spurs the number is usually five or six.

It is shown in Table III that the *number* of leaves in the terminal rosette is not affected by the rootstocks here under consideration. In all cases there are three leaves to each rosette. The size of these leaves, however, *is* affected by rootstock. This in turn affects the total leaf area of the terminal rosette. It is shown than the rootstock M.IX induces the largest area—83·13 sq. cms. This is closely followed by the rootstock M.I with 79·67 sq. cms. The rootstocks M.XII and Bristol 5 give very low values, 44·33 and 55·46 sq. cms. respectively. It will be seen that the rootstocks, when grouped upon the basis of the total leaf area of the " terminal rosette " form the same groups in the same order as when they are classified according to the ratio between mean leaf area and mean internode length. (Table II, section 2.) That is, the leaf area of the terminal rosette is directly related to the known precocity of the rootstocks.

It should also be noted that in the case of M.IX rootstock the leaf area of the " terminal rosette " is much greater in the shorter shoots (groups 2 and 3). That is, as the shoot length falls off the leaf area of the terminal rosette rises. This is not evident in the case of the other rootstocks.

TABLE III.

Showing the total area of the leaves in the terminal rosette of the shoots in the three largest groups.

No.	Stock.	Total Area of all leaves in the terminal rosette.		
		Largest group.	2nd largest group.	3rd largest group.
1	B.5	55·46	49·47	57·34
2	M.XII.	44·33	58·56	51·02
3	M.X.	71·44	72·80	67·57
4	M.IV.	68·41	62·38	76·37
5	M.I.	79·67	75·68	75·59
6	M.IX.	83·13	94·95	102·47

(4) *The relation between leaf area and internode length as shown by correlation coefficients.*

The relation between leaf area and internode length as shown by correlation coefficients is set out in Table IV. Similar tables have been calculated for each rootstock and are almost identical with those of Table IV. The table shows the mean leaf area, mean internode length, the correlation coefficient between them and the probable error of this coefficient for each successive internode.

It is found that there is without exception a very high positive correlation between leaf area and internode length. The probable error figures for this correlation have been calculated and they are sufficiently small to warrant the above statement. In many cases the correlation coefficient is 0·9, which is very high. The fact that internode length and leaf area are so closely associated with each other is a point of fundamental importance in a study of the physiology of fruit trees, since one is a reliable index to the other.

TABLE IV.

Showing mean leaf area and internode length and the correlation coefficient of each successive leaf and internode along the shoots of Worcester Pearmain growing upon Rootstock Bristol 5.

No. of leaf and internode.	Mean leaf Area.	Mean Internode Length.	Correlation coefficient.	P.E. of correlation coefficient.
1	42·5	0·5	Only one leaf.	—
2	31·45	0·4	0·93	±0·061
3	36·59	0·7	0·97	±0·010
4	38·09	1·0	0·86	±0·044
5	32·55	1·7	0·78	±0·052
6	31·69	1·9	0·89	±0·024
7	33·41	1·8	0·91	±0·019
8	35·44	1·9	0·92	±0·017
9	39·51	2·2	0·93	±0·015
10	35·51	2·2	0·93	±0·007
11	35·12	2·2	0·94	±0·013
12	37·66	2·4	0·96	±0·008
13	37·18	2·6	0·94	±0·013
14	36·95	2·6	0·97	±0·006
15	37·01	2·4	0·96	±0·008
16	36·48	2·4	0·95	±0·011
17	36·04	2·4	0·96	±0·009
18	33·08	1·9	0·95	±0·015
19	*55·46	0·8	0·92	±0·018

* = includes mean areas of all leaves in the rosettes.

THE RELATION BETWEEN LEAF SIZE AND VEGETATIVE VIGOUR.

A feature of interest that may be touched upon at this point is the relation that is believed to exist between the size of the sixth leaf from the tip of a shoot and the vegetative vigour of the tree as a whole. Bedford and Pickering (3) claimed that the leaf weight or leaf area of the sixth leaf from the tip of a shoot may be taken as a criterion of the condition of the tree as a whole. Since this theory was formulated, the leaf area and weights of the sixth leaf have been used from time to time for estimating the vigour of the trees.

This theory, however, is not substantiated by the present data obtained on Worcester Pearmain. Table V gives the mean leaf area of all the leaves of the largest group of shoots from every stock included in this experiment, as well as the mean leaf area of the sixth leaf from the tips of the same shoots. It is obvious that the difference between the two means in every case is of sufficient magnitude to disprove the theory that the sixth leaf represents the general vigour of the tree. This is also clearly borne out by the figures given in the last column of Table V, where the leaf area of the sixth leaf is expressed as a ratio of the length of the sixth internode. If Pickering's theory were correct, these figures should agree with those of the previous column in the same table. Clearly they do not so agree, although the two most vigorous stocks show the lowest ratios. In fact, from the data obtained in this study it is doubtful if there is any direct expression of leaf area or internode length which would represent the order of vigour of the trees from whence the shoots were gathered. The nearest approach to a measure of vegetative vigour is given by the ratio of leaf area/internode length. As shown in Table II, a low ratio figure is found in the cases where vigorous stocks are involved.

TABLE V.

Showing the mean leaf area and the area of the sixth leaf from the tip of the shoot.

Rootstock.	Mean Leaf Area. Largest group.	Mean leaf area of the sixth leaf from the tip of the shoot.	Ratio Mean Leaf Area.	Ratio Area of Sixth Leaf.
			Mean internode length.	Length of sixth internode.
B.5	33·16	36·48	18·4	14·0
M.XII.	34·95	39·12	18·0	14·5
M.X.	38·96	43·89	21·6	18·3
M.IV.	39·91	42·36	21·0	18·4
M.I.	41·13	47·13	22·8	18·8
M.IX.	37·22	39·25	26·6	18·7

STATISTICAL ANALYSIS OF LEAF AREA AND INTERNODE LENGTH.

It may be pointed out at this stage that in the presentation of the data regarding internode lengths and leaf areas, no attempt has been made to represent the whole of them statistically. In order to measure the variability of the material under investigation, the probable errors have been calculated in the case of both the internode lengths and leaf areas of all measurements made on the shoots growing upon M.IV. These are given in Table VI. It is shown that for leaf area the largest probable error is ± 1·18 sq. cms. on a leaf area of 45·97 sq. cms. This represents an error of slightly less than 3 per cent. In the case of internode length the greatest error is ± 0·12 cms. on a mean internode length of 2·3 cms. This represents an error of a little over 5 per cent.

Clearly the probable errors shown in Table VI both for the mean leaf areas and internode lengths are so small that it is considered unnecessary to make similar calculations for the remaining stocks. In view of the small probable errors as shown for M.IV in Table VI, the variations between the different stocks which have been stressed in the foregoing pages are all considered to be of sufficient magnitude to permit a discussion on these points without further statistical analysis.

Table VI.

Showing the mean leaf area and internode length of the largest group of shoots of Worcester Pearmain growing upon the rootstocks Malling IV. Also the probable errors of these means.

No. of leaf and internode.	Mean Leaf Area.	Probable Error.	Mean Internode Length.	Probable Error.
1	—	—	0·5	0·00
2	—	—	0·5	±0·06
3	—	—	0·9	±0·05
4	37·33	±1·02	1·5	±0·03
5	32·58	±0·71	1·9	±0·03
6	34·81	±0·77	2·3	±0·12
7	38·25	±0·30	2·4	±0·03
8	40·07	±0·68	2·0	±0·08
9	44·14	±1·14	2·5	±0·07
10	46·16	±1·15	2·4	±0·07
11	45·50	±1·05	2·3	±0·10
12	45·97	±1·18	2·6	±0·07
13	43·88	±1·03	2·5	±0·06
14	44·13	±0·96	2·4	±0·06
15	44·46	±0·92	2·4	±0·07
16	45·44	±0·97	2·3	±0·09
17	45·19	±0·94	2·4	±0·06
18	42·36	±0·68	2·3	±0·10
19	41·78	±0·80	1·5	±0·06
20	38·59	±0·82	1·4	±0·05
*21	68·41	±2·19	0·6	±0·05

* = includes the mean areas of all the leaves in the rosette.

Discussion.

A study of the relationship between growth characters and fruiting potentialities is one of the important aspects of applied plant physiology in horticulture. A clear demonstration of the kind and quality of growth that is associated with productivity in the different varieties of apple trees would go a long way towards reconciling any conflicting ideas concerning the relation between growth and fruitfulness in a tree. It would also furnish valuable diagnostic features for practical orchard culture. Given a knowledge of the relationship between certain readily distinguishable growth characters and productivity in fruit trees, the aim of cultural operations could then be made more direct and effective towards attaining the desired end. It is, as Chandler (5) has already pointed out, only by supplementing field experiments with physiological studies designed to furnish a better understanding of the tree processes that a more complete cultural practice can be achieved.

The data given in the foregoing pages of this report sets forth the effect of rootstocks upon the leaf area and internode length of the current season's shoots. Barker and Lees (2) have quite rightly emphasized the idea that although a fruit tree is a single complete organism, yet a clearer understanding of its processes may be obtained in the first place by regarding it as a colony of somewhat competing units.

The importance of the relationship between growth and performance has been shown by Hooker (16), and Maney and Plagge (20) have found a marked correlation between terminal twig growth and fruitfulness. Heinicke (15) has stressed the importance of spur growth in relation to fruit setting, while Yeager (29) has also noted a marked correlation between spur length and productivity. The work of Roberts (22, 23, 24) and Dorsey (6) along the same general lines gives ample confirmation of this relationship. Gourley (10) goes so far as to assert that " the daily twig growth shows a rate and amount of growth closely commensurate with the yielding power of the trees." Harley (13) in his studies upon the normal variation in the chemical composition of bearing and non-bearing apple spurs places particular emphasis upon the uniformity of the growth length of the spurs in order to get comparable material. Further evidence, if it were needed, is supplied by Hooker (16) and by Edminster (7), who found a high degree of correlation between the length of shoots and the percentage of the lateral buds which formed fruit spurs.

In the variety of apple Worcester Pearmain, the current year's shoot is an important element in production, since as much as 50 per cent of the crop may be produced on one-year wood. It is to be expected, therefore, that the relation between growth and productivity shown by the various workers cited in the preceding paragraph should hold in the case of the one-year-old shoots of Worcester Pearmain.

It would appear, therefore, that the marked difference between the mean internode length of the shoots upon the most precocious rootstock—M.IX—and that of the other stocks included in this study, points to a relation between internode length and precocity. It is impossible to assert that such a relation is absolute, since the precocity of M.IX may also be related to other factors such as *rate* of growth, *season* of growth, and leaf area. The next step, clearly, is to study how far precocity can be attributed to each of the above as contributory factors towards the goal of fruit growers—productivity.

It is well known that the growth curves of shoots show marked periodicity, and follow the curves for the Sachs' Grand Growth Period. The data presented earlier in this paper shows that this growth cycle is clearly expressed in the internode lengths along a shoot. The data show an early falling off in the internode lengths of shoots where M.IV is the rootstock. In the cases where M.IX is the rootstock there is also an early falling off in internode length, but, furthermore, the internodes are never so long as in the other cases. Swarbrick (27) and others in their studies of growth curves have pointed out a possible relation between an early fall in the growth curves and fruit bud formation. The early falling off in the internode length of shoots upon M.IV as a rootstock points to a definite contributing internal condition in these trees, and one which may lead to increased terminal and axillary blossom bud formation, this notwithstanding the fact that the shoots have made very long extension growth earlier in the season. The modification of the periodicity of internode length appears to be another way in which rootstocks may modify growth and thereby induce precocity or fruitfulness in the trees. It is now established that trees upon M.IV rootstock make big trees, but that they are at the same time precocious. The data given above would supply a reason for this.

Leaf area is clearly related to the production of carbohydrates and synthetic plant products generally, and in this way leaf area is undoubtedly directly related to the amount of reserve carbohydrates stored in woody stems. Variations in leaf area are known to have a profound effect upon flower bud formation. The data presented by Roberts (22, 23, 24), Magness (18, 19), Goff (8), Gourley (9) and Swarbrick (26) has clearly demonstrated that a direct relation exists between leaf area and flower bud formation. Since leaves constitute such a large part of the fruit spur system and the current year's growth, any factor which affects leaf area may also be expected to affect fruit production.

The importance of local or adjacent leaf area upon flower bud production is stressed by several of the above cited workers. Pickett (21), in his study upon strawberry plants, showed that a strict correlation exists between total production of fruit and the total amount of foliage per plant. Hence factors affecting leaf area are important.

Since emphasis has been laid upon the adjacent leaf area in flower bud production it would follow that leaf area ought to be studied in relation to the amount of tree which it has to serve. In other words, leaf area relative to internode length may show a closer correlation with productivity than either individual leaf size or the total leaf area of the tree expressed in square centimetres. It has been shown in a previous section that the ratio mean leaf area to mean internode length shows a clear correlation with the known precocity induced in a scion by a rootstock. The more precocious trees are shown to have the larger leaf areas per unit length of shoot, particularly as the season advances.

It has also been shown in this study that the rootstocks affect the leaf area of the rosette of leaves which terminates the current year's shoot. In the case of the " vigorous " rootstocks the leaf area of this rosette is small by comparison with that of some of the other stocks. The amount of terminal blossom bud formation seems to be directly related to the leaf area of the terminal leaf rosettes. A similar relation between blossom bud formation and leaf area at the tips of current year's shoots has also been pointed out by Roberts (24).

A high positive correlation exists between leaf area and internode length. It is extremely interesting that this high correlation should be shown in all cases, since it would indicate that both leaf area and internode length are affected in the same way by the internal condition of the plant. This high correlation would also suggest that the leaf and its internode constitute a physiological unit and a study of one will give an index to the condition of the other. It is most interesting that the correlation should be equally high in the case of M.IX, where the mean internode length is only 1·4 cms, as in M.XII, where the internode length is 1·9 cms. The establishment of this high positive correlation between leaf area and internode length is one of the most clear-cut contributions arising from the present investigation.

It is interesting and important to note that there is no obvious regular direct relation between the vigour of a tree and its leaf size. The data show clearly that the rootstocks M.XII and Bristol 5, rootstocks which are associated with the largest and most vigorous growing trees included in this study, are the ones which have the smallest mean leaf size. The mean leaf area in these two cases is 34·95 and 33·16 sq. cms. respectively. Even the dwarfing rootstock M.IX induces an average leaf size of 37·22 sq. cms., which is about 2·2 sq. cms. larger than the leaves of the most vigorous stocks. It is clearly evident that the vigorous trees have *more* leaves per tree, but they have also *more* woody tissue in their framework and longer internodes, so that these leaves have a much larger amount of woody tissue to support and build up before any foodstuff is left over for storage. This fact is important and raises the question of the effect of ringing and sod culture upon the internode length and leaf area of the trees under treatment. Does the ringing or sod culture—practices which we know reduce extension growth—increase flower bud formation by first of all decreasing the internode length more than leaf area and in this way raise the ratio of leaf area to internode length ? Clearly this point must be investigated: if it be established, it will add convincing evidence in support of the suggestion that the ratio of leaf area to internode length is an important consideration in the productivity of fruit trees.

A further interesting point in the relation of leaf size to vegetative vigour is the fact that leaf size cannot be used directly to measure the vegetative vigour of the tree as a whole. Pickering's (3) suggestion that the sixth leaf from the tip will give such a measure is not supported by the data collected in this study. Since a large number of leaves are here under review, the point would appear established and Pickering's suggestion cannot be regarded as universally valid.

In the case of Worcester Pearmain here under study, neither the mean leaf area, mean internode length, nor apparently any particular leaf such as the sixth from the tip, can be used as an index to the vigour of the tree as a whole. The apparent absence of a direct relation between leaf size and vegetative vigour is perhaps a little surprising, but the data here presented show beyond doubt that no obvious direct relation can be found. A reliable measure of vegetative vigour must be sought elsewhere than in a direct comparison of the mean leaf area or mean internode length, or that of any other selected leaf area or internode. The *ratio* mean leaf area/mean internode length is a better index than leaf size taken alone.

This study raises interesting points which must be further investigated before definite conclusions can be drawn from the data to hand. The relative growth rates of the shoots upon the various stocks is one such problem. Swarbrick (27) has shown that the shoots where M.IX is the rootstock cease growing very early in the season. The relation between internode length, leaf area and lateral or axillary blossom bud formation is another. The effect of the same rootstock upon the morphology of apple varieties with very diverse habits is another. Such problems raise fundamental questions of the relation between internal condition and external morphology. The work will obviously need to be supplemented with chemical investigations in conjunction with studies such as those attempted in this paper.

One further point remains to be raised. Environmental conditions affect the response which a scion makes to rootstock influence. Brown (4), for example, shows clearly that rootstock and scion relationship depends to a very large extent upon local conditions and climatic factors, and rootstocks suitable for known varieties of citrus in India are not suitable for the same varieties in California. Barker and Lees (1) have also emphasized the effect of the local conditions at Long Ashton upon the type of growth made by plums and apples. It is reasonable to suppose, therefore, that climatic and local conditions may also affect leaf size and internode length and in this way affect potential cropping capacity. In any case the present investigation has shown that there is a definite relation between productivity and the ratio between leaf and internode length. It has also shown that the vigour of a tree cannot be estimated from measurements of leaf size or internode length. It should be noted, however, that the Long Ashton conditions are characterized by a much higher rainfall than that of the East of England. The data and conclusions should be studied with this knowledge in view.

The study also establishes more firmly the viewpoint that the practical problem of inducing productivity in fruit trees will be most surely advanced by a closer study of the growth features which are invariably associated with productive potentiality.

SUMMARY.

Observations on the internode length and the leaf area of the current season's shoots of Worcester Pearmain apple trees worked on the rootstocks M.I, M.IV, M.IX, M.X, M.XII and Bristol 5, respectively, have been made.

The mean internode length of the current season's shoots is definitely shorter in trees worked on M.IX than on the other five rootstocks. The range of variation in the internode lengths between the other five stocks does not appear significant so that as regards internode length they form a group distinct only from M.IX.

The current season's shoot may be divided into three definite growth periods and the " Sachs' Grand Period of Growth " is expressed very graphically in the prevailing internode lengths of each part of the shoot.

Trees on M.IV have shoots which are characterized by an early falling off in internode length, although these shoots make vigorous extension growth earlier in the season. This early falling off in the internode lengths points to a definite internal condition in these trees which may be connected with the increased terminal and axillary blossom bud formation associated with this rootstock.

In trees on M.IX, the long internodes are confined to a very narrow region of the shoot, and this region occurs relatively *late* in the life history of the shoot. This peculiarity of M.IX, coupled with its relatively short mean internode length, appears closely related to the known precocity of this stock.

The difference between the " actual " and " calculated " leaf area in the variety Worcester Pearmain is shown to be less than the possible error introduced by the difficulties of accurate measurement in the field.

M.I induces a larger leaf size than any of the other stocks here under review. M.IX, however, produces the largest leaf area per unit length of shoot. M.XII and B.5, though known to be most vigorous stocks, produce the least mean leaf area and the least leaf area per unit length of shoot. M.IV and M.X form an intermediate group between M.IX and M.XII with leaf areas slightly more than those in trees on M.XII and B.5, but less than on M.I and M.IX. These larger relative leaf areas appear to be definitely associated with the known precocity induced in the scion by these rootstocks. The vegetative vigour associated with B.5 and M.XII as represented by the total shoot growth made from year to year is not directly proportional to the size of the leaves, thus indicating that there is no regular direct relation between the vigour of a tree and its leaf size.

A definite relationship is established between the total leaf area of the terminal rosette of leaves and the precocity of fruiting, particularly in the terminal position.

It is shown that when the figures for mean leaf area and mean internode length are expressed in ratio form there is a direct correlation with the known precocity and fruitfulness induced by the rootstocks here under study.

A high positive correlation is shown in all the rootstocks between internode length and leaf area. This definite correlation is of great interest and practical importance, in that a measure of one becomes a reliable index to the other.

The theory that the sixth leaf from the tip of a shoot may be used as an index to the general vigour of the tree is clearly not valid for the present material. It appears doubtful whether there is any direct measurement of leaf area that can be used to express the order of the vigour of the trees from whence the leaves are gathered.

It is shown that rootstocks may modify internode length and leaf size. The ratio mean leaf area to mean internode length appears directly related to precocity of flower bearing. A combined seasonal chemical and morphological investigation along similar lines to the present study is indicated. The effect of " sod mulch " and " nitrogen starvation conditions " upon leaf size and internode length and its relation to flower production is also raised. It is hoped to continue further investigations along these lines as opportunity affords.

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(*Received* 3/32.)

SUPPLEMENTARY NOTE ON PLUM BACTERIAL CANKER.

By H. WORMALD,

East Malling Research Station, Kent.

An account of the symptoms of Bacterial Canker in plum trees appeared in an earlier number of this Journal (3). The relation that Bacterial Canker bears to " Dieback " was discussed, and various explanations that had been put forward previously to account for Dieback in plum trees were reviewed.

Since that paper was published the writer's attention has been drawn to two articles by Bedford and Pickering (1, 2), who describe a " Canker in Plum Trees " seen at Harpenden and Woburn during 1895 to 1898. They sought advice from various sources as to the cause of the cankers and the reports they received diagnosed the damage as caused by *Nectria ditissima, Micrococcus dendroporthes,* and *Eutypella prunastri,* respectively.

From Bedford and Pickering's description it seems certain that the disease they saw is the one now known as Bacterial Canker, particularly with regard to the way in which the trees died quickly in the course of one season, and the inhibition in the development of the cankers during the summer. Thus they write (2), " In one case a tree, with a stem some three inches in diameter at the base was so badly attacked throughout, that the amount of sound wood left was not thicker than a lead pencil, yet this tree grew and fruited for two years afterwards, and died only through being broken in two by the wind." In the paper on Bacterial Canker, referred to above, the writer described a very similar case of a plum tree, with a canker nearly three feet long but not quite girdling, surviving two summers and finally being broken across in a gale.

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(*Received* –/3/32.)

A NOTE ON THE TOXICITY OF MINERAL OIL SPRAYS TO VEGETATION.

By F. TUTIN,
Long Ashton Research Station.

FOR a number of years past spray mixtures prepared from certain high-boiling " mineral " oil fractions have been used to a considerable extent in the United States of America and other countries for the control of certain insect pests. Perhaps the greatest use of these sprays has been for the control of pests such as scale insects on *Citrus* trees and on vines during the dormant period. During more recent years, however, " mineral " or " white oil " sprays have also been used in this country, both as winter washes and for summer use for the control of such pests as aphis sp. on English fruit trees. In some cases, however, considerable damage to vegetation has resulted, evidently owing to the spray mixture having been prepared from an oil of unsuitable quality, but in many instances quite satisfactory results have been obtained. Judging from inquiries received, both from fruit growers and from spray manufacturers, there appears to be comparatively little current knowledge in this country regarding the characteristics of a " mineral " oil which indicate that it would be unfit for use in the preparation of a summer spray on account of its toxicity towards vegetation. The object of the present paper is, therefore, to supply such information as will act as a guide in the selection of an oil suitable for use as a summer spray.

All " mineral " oils in their natural state consist of very complete mixtures of compounds and have a very wide range of boiling point. The oil generally used for the preparation of spray mixtures is obtained from a fraction boiling from about 300 to 400°C. The composition of such a fraction may vary greatly according to the source of the original oil from which it was obtained, but for our purpose it may be considered to consist essentially of three components, namely : paraffin hydrocarbons ; olefines, or unsaturated, hydrocarbons ; and aromatic hydrocarbons. Of these three components the paraffin generally preponderates, and it is this component which is desired for the preparation of an oil spray for summer use. Paraffin hydrocarbons are substances of great chemical stability, a fact from which they derive their name, and are consequently generally devoid of toxic action. They appear to be capable, however, of killing certain insects and certain insect eggs by virtue of the smothering action which they exert. The olefine hydrocarbons, on the other hand, possess considerable chemical activity by virtue of their unsaturated nature and, in consequence of this, they are in general highly toxic to vegetation. A striking example of the toxicity of an olefine to vegetation is afforded by the use of a small concentration of ethylene, the lowest member of the olefine series, to cause artificially the rapid ripening of fruit. A very low concentration of ethylene in the atmosphere will also kill plants, root development being at once stopped. It is owing to this fact that plants do not thrive in an atmosphere contaminated with even minute traces of coal gas. The toxicity towards plants of the higher olefine hydrocarbons is well exemplified by the fact that mineral oil products consisting essentially of such compounds have been used in America as weed-killers and have been stated to be as efficient for this purpose as are arsenites. (Compare, Gray and de Ong, *J. Indust. and Eng. Chem.*, 1926, p. 175.)

With respect to the aromatic hydrocarbons present in a " mineral " oil fraction, these may not, themselves, be so toxic to plants as are the olefines, except in so far as they contain unsaturated side chains. Aromatic hydrocarbons, however, have a much lower viscosity than do the paraffin compounds of similar boiling point and their power of penetrating plant tissues is much greater than the penetrating power of paraffins. This may be owing to the fact that a much larger proportion of the cell contents of leaves is soluble in aromatic hydrocarbons than in paraffin hydrocarbons of the same boiling point. In a case investigated by the present author it was found that the aromatic hydrocarbon, benzene, would dissolve an amount of material representing nearly 20 per cent of the weight of the dried leaves of *Eriodictyon Californicum* whilst only about 2 per cent was dissolved by a " mineral " oil fraction consisting of paraffin hydrocarbons boiling at about 80°C. Whatever may be the correct explanation of the behaviour of aromatic hydrocarbons towards living plants, the fact remains that they cause very serious damage indeed except when employed in the form of a winter wash on deciduous trees and shrubs in a strictly dormant condition.

From the above considerations it is evident that in order to render a " mineral " oil fraction suitable for use as a summer spray it must be treated in some way so as to deprive it of its unsaturated and aromatic constituents. This is usually accomplished by suitable treatment by sulphuric acid, which dissolves by sulphonation the undesirable constituents and leaves the paraffin hydrocarbons unaffected. The more thorough is the treatment with sulphuric acid the purer is the residual paraffin, but this naturally results in the purer products being more expensive. An opinion regarding the suitability of a given oil for use on growing plants may therefore be formed by estimating the percentage of unsulphonatable material which it contains, which should, of course, be as high as possible. This estimation is usually conducted by the method described by Gray and de Ong (*loc. cit.*) which is as follows :—

ESTIMATION OF UNSULPHONATED RESIDUE.

Both fuming and ordinary concentrated sulphuric acids are required. The concentration of these should be accurately estimated by titration, after which the two acids should be mixed in such proportions that they will give a product exactly 37 Normal. Five cc. of the oil to be tested are then placed in a " 30 or 50 per cent Babcock cream test bottle " and 10 cc. of the acid added. The mixture should then be shaken vigorously for two minutes, after which a further 10 cc. of acid are added and the mixture again shaken for two minutes. The bottle and contents should then be heated to 95-100°C. for one hour, shaking every ten minutes. After cooling, ordinary concentrated sulphuric acid is added so as to bring the oil which separates on the surface up into the graduated neck of the bottle when, after centrifuging for five minutes, the volume of the unsulphonated residue may be read off.

IODINE VALUES.

The above described method of evaluating an oil for use in summer spray mixtures is somewhat cumbrous and can only be employed where a well-equipped laboratory is available. It therefore seems desirable to employ a more simple method if possible. A determination of the " iodine value " of an oil forms a ready means of obtaining an indication of the amount of unsaturated material present and involves the use of ordinary apparatus only. Of course the " iodine value " does not indicate directly the proportion of aromatic compounds present in the sample of oil under examination, but since the aromatic and unsaturated compounds are both removed together by the same process of purification to which the original crude oil is subjected it follows that the " iodine value " may be expected to give a fairly reliable indication of the degree of purification to which the oil has been subjected. This conclusion appears to be fully borne out by the results of the field trials described below. When conducting the determinations of the " iodine values " it is important to bear in mind that these estimations should be conducted by the method of Hüble or that of Wijs and *not* by the Hüble-Waller method, since the latter, where used for " mineral oils," gives figures considerably below the correct values. Full details of all these methods will be found in *Chemical Technology and Analysis of Oils, Fats and Waxes*, Vol. I, by Lewkowitsch and Warburton.

FIELD TRIALS.

For the purpose of field trials a series of five oils were employed, some of the characters of which are shown in Table I :—

In order to compare the toxicity of these oils towards vegetation emulsions of each were prepared in 3, 1·5 and 0·75 per cent concentrations. The emulsifier used in the first instance was Agral W.B. since this agent affords by far the most

TABLE I.

	Specific Gravity 60° F.	Viscosity (Redwood) 70° F.	Flash Point (open)	Iodine Value (Wijs).
No. 1. White Oil (No. 24165) ..	0·865	120″	(high)	0·03
No. 2. White Oil (No. 24138) ..	0·887	500″	(high)	0·07
No. 3. P.2. (No. 105)	0·860	125″	310° F.	1·2
No. 4. Half White (No. 1301) ..	0·875	160″	310° F.	7·0
No. 5. Pale Spindle (J.D.2.) ..	0·906	160″	350° F.	16·4

ready method of preparing good emulsions on a laboratory scale and experience has shown that it has no effect on growing plants. The proportion of Agral W.B. used was in each case 15 per cent by volume of the oil employed. The resulting emulsions were in all cases quite stable on keeping and when sprayed on to foliage gave an excellent " cover." Shoots of the apple, Reinette L. Kowiski, were thoroughly sprayed with each of these preparations about the middle of July, strong " leaders " that were still in active growth being selected. In no case did damage appear immediately but observations were continued for more than three weeks. The damage to the foliage eventually caused may be summarized as follows :—

TABLE II.

Oil.	Concentration.		
	3 per cent.	1·5 per cent.	0·75 per cent.
No. 1	Nil.	Nil.	Nil.
No. 2	Very slight damage to the tips of a few of the youngest leaves.	Nil.	Nil.
No. 3	A small amount of general damage, but not serious.	Slight damage.	Nil.
No. 4	Decidedly greater general damage, but no leaves killed.	Some general damage.	Slight damage.
No. 5	Extensive damage, many leaves being eventually killed.	Fairly severe general damage.	General Damage.

It will be seen from these results that the degree of toxicity towards vegetation shown by these five oils respectively is quite in harmony with their respective " iodine values " as shown in Table I. The conclusion drawn from these results is that it is not advisable to use for a summer spray an oil having an iodine value higher than 1·0 when the concentration of oil in the spray mixture is 3 per cent or greater.

Other trials were conducted later on several different varieties of the apple and also on a number of other species of plants but only small differences in their susceptibility to damage were observed, except in the case of the Black Currant, which proved markedly more resistant to damage by an oil spray.

EFFECT OF EMULSIFICATION METHOD.

As previously mentioned, the trials described above were conducted with emulsions made with the aid of Agral W.B. This method has been called the " two solution " method since it is necessary to add a solution of the requisite amount of alkali to the mixture of spray concentrate and water in order to form an emulsion. (Compare Staniland, Tutin and Walton, *Journ. of Pomology and Hort. Science*, 1930, VIII, 132.) This method, although it yields most satisfactory emulsions, has a disadvantage when used with " mineral " oils. Agral W.B. will mix readily, on agitation, with all " mineral " oils, but in the case of the more highly purified oils the greater part of it separates again after standing for a few hours. Of the oils used for the experiments described in this paper only the Pale Spindle Oils, J.D.2, would form a permanent solution with Agral W.B. It was therefore decided to conduct experiments with emulsions prepared by different methods from the same oils. In addition to the above mentioned emulsions made by the " two solution " process, a second series of spray mixtures was made from a concentrated emulsion containing 80 per cent of oil which had been prepared with the aid of glue and the neutral sodium salt of an alkylated sulphonic derivative.* A third series was prepared from a concentrate made by dissolving 15 per cent of an oil-soluble neutral sodium salt of a sulphonated product in the " mineral " oil to be used. Such a solution gives an emulsion on simply mixing with water.

Trials conducted with emulsions made by the second method gave results showing no detectable difference from those obtained when Agral W.B. was used. The apparent " cover " given to the foliage by spray mixtures made from the concentrated emulsion appeared, however, to be much inferior to that obtained when the " two solution " method was employed, despite the fact that the concentrations of oil in the respective sprays were identical.

When trials were made with the spray mixtures made by the third method very serious damage resulted in all cases, even when the White Oil No. 24165 was employed, although this oil had caused no damage when emulsified by either of the former methods. When a mixture containing 3 per cent of the oil was used damage was obvious within one hour and most of the leaves were eventually entirely killed. Curiously enough it was only the young, half-grown leaves that survived. These results at once suggested that the emulsifier used was toxic to vegetation. Shoots of the same apple tree previously used were therefore sprayed with aqueous solutions of the emulsifier only, in 0·5, 0·25 and 0·125 per cent concentrations respectively. A fair amount of spotting of the

* This process will be described in more detail in a subsequent communication.

leaves was caused by the solution of highest concentration, some damage by the solution containing 0·25 per cent, but no damage was produced by the 0·125 per cent of the emulsifier. In all cases, however, when these same concentrations of emulsifier were employed together with the oil in the respective concentrations of 3, 1·5 and 0·75 per cent, very much greater damage resulted despite the fact that the oil appeared to be non-toxic when emulsified by other methods. In the case of the weakest concentration, neither the oil nor the emulsifier caused damage when used separately, but when employed together quite serious damage resulted. This indicates that considerable caution must be exercised in selecting emulsifiers for spray mixtures.

SUMMARY.

It is shown that the " iodine value," as determined by the Hüble or Wijs method, may be taken as an index of the toxicity of a " mineral " oil towards vegetation.

The " iodine value " of an oil is more easily estimated than is the " unsulphonatable residue " and appears to give information of equal value.

The conclusion is drawn that it is not safe to use an oil having an " iodine value " greater than 1·0 for the preparation of a summer spray mixture having an oil content of 3 per cent. It is impossible, however, to state positively that every " mineral " oil having an " iodine value " of 1·0 or less will be safe for use on growing vegetation.

It is pointed out that caution is necessary in choosing the method of emulsification of an oil spray, as damage to foliage may result from the use of an unsuitable emulsifier even with a non-toxic oil.

(*Received* 31/3/32)

THE SCAB FUNGUS (*VENTURIA INÆQUALIS*) ON APPLE SHOOTS.

By R. W. Marsh and Mary M. Walker,
Long Ashton Research Station.

I. INTRODUCTORY AND HISTORICAL.

The opening sentence of a note published by Berkeley in 1855 reads, " Why do apples and pears crack and put on the appearance of rifted bark ? " Apart from this early allusion to scabbed wood, no reference to this phase in the life history of the apple scab fungus has been found previous to the publication of short papers by Sorauer (1890) and Cuboni (1892). Cuboni demonstrated the overwintering of the fungus in the form of stromata beneath the bark, and the production, under humid conditions, of conidia from these resting bodies. Aderhold (1896) in his classic paper on the scab fungi dismissed shoot infections on apple as unimportant and remarked that they had not been found in his investigations.

Muller-Thurgan (1902), working at Wädenswil, found that scab caused much damage to the wood, particularly in Eastern Switzerland. He recorded the appearance of spores on scabbed wood before the middle of March.

In South Africa, Lounsbury (1905) considered that apple scab had been introduced on nursery stock and that it overwintered chiefly on the twigs.

The first comprehensive accounts of apple scab in England were given by Salmon (1906 and 1908). He published photographs of scabbed shoots and a section of a stroma producing spores in the spring. He noted that the effect produced on the shoots was modified by variety of the host and by the virulence of the disease : on Cox, a conspicuous blistered appearance resulted ; on Wellington, smaller scattered pustules ; and on Lord Suffield the bark was badly ruptured and tended to peel off. The following varieties were recorded as susceptible to scab infection on the twigs : Yellow Ingestre, Cox's Orange Pippin, Lord Suffield, Ecklinville Seedling, Wellington, Cox's Pearmain, Warner's King, Mr. Gladstone, Councillor, White Transparent.

Massee (1910) described scab on the shoots as a cause of serious injury, the affected bark being " torn into shreds." He pointed out the importance of scabbed shoots as a source of infection and advocated their removal as a practicable means of controlling the disease.

Scabbed shoots were recorded in France by Griffin and Maublanc (1905) and in Denmark by Eriksson (1911). Eriksson remarked that scab is frequently observed, but only on twigs of the current year's growth.

In 1907, 1910 and 1912 papers were published by Voges on shoot infections as found in the Hildesheim district of Hanover. He emphasised the parasitic nature of the fungus on the shoots and gave accounts, with figures, of the appearance of scabbed shoots in winter and in spring. The scab lesion in winter was depicted as a pustule-like, ellipsoid outgrowth in the periderm having a longitudinal slit with tattered margins between which the stroma showed as a crumbly mass. Near the main lesion, blister-like small pustules were found, as yet unopened. Voges stated that the stroma was composed of radially arranged rows of cells and bore (in May) conidia on the outer surface, while the inner surface gave off slender strands which grew between and killed the cells of the collenchyma. He noted the presence of a barrier of wound cork at the boundary of the diseased cells and called attention to the excessive transpiration of the attacked tissues, leading frequently to the death of the twigs.

In the United States, records of scab infection on shoots have been relatively infrequent. In 1899 Stewart and Blodgett recorded scab on twigs of the Ladye apple in the Hudson Valley and in 1904 Lawrence noted shoot infection in Washington. Wallace (1913), after summarising the evidence, concluded that infected shoots were of little importance in the overwintering of the scab fungus. Morse and Darrow (1913) considered that in certain seasons twig infections might be of importance especially on watersprouts. They laid particular stress on the overwintering of conidia produced on scabbed wood in the previous autumn. Morris noted shoot infections in Montana in 1914 and Cook and Schwarze (1917) recorded scabbed twigs in New Jersey producing spores in April from stromatic tissue.

In 1925 Cunningham noted varietal differences in shoot infection in New Zealand. On some varieties the infection took the form of small pustules, on others the infections were spreading and superficial and on others large blisters and flaking of bark resulted. The attack was worst on vigorously growing shoots and on water shoots.

Recent references to this subject in England have been made by Wiltshire (1922) and Moore (1930, 1932). Wiltshire made clear the importance of scab wounds in shoots in providing opportunity for infections with the apple canker fungus. Moore gave the effect of various spray treatments on scab infection of the twigs of Cox's Orange Pippin and remarked on the dispersal of spores from scabbed wood as follows : " In 1928 viable spores were found in lesions on the young wood of a control tree of Cox's Orange Pippin . . . on January 17th. Several scabbed Cox trees in pots were sprayed at that time with various winter washes, but at the ' pink bud ' stage it was observed that fresh splits in the bark had occurred close to the original lesions and viable spores were freely being produced while the winter washes still coated the bark. Sections of some of the lesions were cut and stained in cotton blue, when it became quite evident that the lesion was not a single ‘ pad ’ of mycelium but was made up of layers of pads, separated from each other by corky tissue. The outermost pad liberates its spores first, quite early in the year, and then becomes dry and hard. It is followed later on in turn by the two subjacent pads and these split the bark laterally to the primary one and liberate their spores later in the year.” In a more recent article by Moore (1932), figures illustrating this point are given.

The attention of the present authors was called to this subject by observations made (Marsh, 1931) in West of England orchards where it was found that the spore material for spring infections of scab was coming exclusively from the infected shoots. A consideration of the literature quoted above showed that while the morphology of the scab pustules in the spring had received frequent study, the early stages of shoot infection had not been described. Investigations were therefore directed particularly to following the course of infection and the conditions affecting its success. The resulting reactions of the host were studied in several apple varieties. Further records were taken of spore production from infected twigs and the life history of the scab pustules on the wood was followed to its conclusion.

II. EXPERIMENTAL.

(a) MATERIAL AND METHODS.

For the most part, observations were made and inoculations carried out in the plantations of the Long Ashton Research Station, but, for comparative purposes, shoots have been examined from other Somerset orchards and from Worcestershire and Herefordshire. Scabbed wood was noted during 1931 on the following varieties mentioned by Salmon (1906): Lord Suffield, Cox’s Orange Pippin, Ecklinville Seedling, Wellington and Warner’s King; and, in addition, on Worcester Pearmain, James Grieve, King of the Pippins, Bismarck, Blenheim Orange, Lane’s Prince Albert, Allington Pippin, Stirling Castle, Macintosh Red, Sweet Alford, Major, Coronation, and various unnamed seedlings. Material for study was obtained from naturally-occurring infections on these varieties and also from shoots of both susceptible and resistant varieties which had been inoculated by placing drops of a conidial suspension on the unwounded epidermis. In carrying out inoculations, conidia from young leaf pustules were employed and the portions of shoots inoculated were kept moist by being enclosed in glass cylinders (3 in. by 1 in.). These cylinders were removed approximately a week after inoculation. Inoculated portions of shoots were taken at three, seven and twelve days after inoculation and fixed in 1 per cent chrom-acetic acid. Sections were stained either in iron alum-hæmatoxylin or in lacto-phenol + cotton blue followed by Sudan III.

In using the latter combination of stains for microtome sections, the slides were first stained with cotton blue using the method suggested by Hough (1930), with the modification that all solutions were made up with twice the stated volume of methylated spirit. A saturated solution of Sudan III was prepared by boiling the solid in a mixture of one volume of glycerine to two volumes of absolute alcohol and the slides were placed in this solution and heated to about 70°C. for a few minutes. They were then cooled slightly and placed in a mixture of one volume of glycerine to two volumes of absolute alcohol. After immersion for one minute, with gentle shaking and warming, the slides were drained and the sections finally mounted in glycerine jelly ; or, after dehydration, mounted in Canada balsam.

(b) DETAILED RESULTS.

It has been noted by previous writers that the effects of scab attack on the shoots are not the same in all varieties of apple. There is also observable, even within a single variety, considerable diversity in the course of an attack, depending on the time of the year and the stage of shoot development at which infection takes place. For the sake of clearness, the method of presenting the facts observed will be, first, by a description, for the variety Lord Suffield, of the type of infection which persists through a cycle of development from one summer until the next. Some of the conditions determining or modifying the course of infection in this variety will then be stated, and records of spore dissemination from infected shoots will be given. The course of scab attack on the shoots of the varieties Cox, Worcester and Lane will then be compared with that on Lord Suffield.

(i) *The full infection cycle on the variety Lord Suffield.*

The first stage in infection is the germination of the scab spore and penetration of the cuticle of the host. These processes have been fully described by Wiltshire (1922) for leaf infections and his description holds good in all essential respects for infections on the shoot. The only noteworthy departure from the course of events recorded by Wiltshire is that in shoot infections the appressorium is little developed and sometimes absent.

Given suitable conditions for infection, the spore in contact with the surface of the green apical portion of a growing shoot sends out an infection hypha which pierces the cuticle and thus reaches the outer cell walls of the epidermis. This epidermis, in the apple shoot, remains a meristematic layer, forming, usually at a short distance from the shoot tip, the phellogen which gives rise to the cork cells of the primary bark. The infection hypha, growing between the cuticle and the epidermis, first branches to form a thin plate of cells. Tangential divisions of the fungus tissue then bring about the formation of a lens-shaped pseudoparenchyma forcing the epidermis and the cuticle apart. The epidermal cells in contact with the fungus tissue collapse and, by the end of a week after the first penetration of the cuticle, these cells are invaded and occupied by the fungus (Fig. 1).

The pseudoparenchyma continues to spread laterally at the margin of the infection, while conidiophores form on the outer surface of the oldest part of the fungus tissue, and make their way through the overlying cuticle. At a slightly later stage the sub-epidermal cells are in their turn killed while the formation of conidiophores continues to extend towards the margin of the infection. The subcuticular growth of the fungus is eventually circumscribed by the formation of normal cork from the surrounding healthy epidermal cells. The infected tissues being unable to participate in this cork formation are left as a gap in the bark, the gap being filled by the pseudoparenchyma of the fungus (Fig. 2).

Although the spread of the fungus on the exterior of the shoot is thus arrested, further centrifugal growth of the mycelium takes place in the phellogen tissue which abuts on the infected area. This invasion of the phellogen may at times take place after very little superficial growth. Thus if the cuticle is penetrated by the fungus only a short time before cork formation starts in that region, the laying down of cork cells will be in progress around the point of infection before the fungus has been able to invade more than a few epidermal cells. The subcuticular infection is thus quickly restricted and few conidiophores are formed, but the infection extends internally by growth in the phellogen layer (Fig. 3).

Once established in the phellogen tissues, the fungus develops both laterally and radially to form a relatively thick pad of fungus tissue (stroma) beneath the bark. This stroma extends at its periphery by invading and destroying the thin-walled meristematic phellogen cells, and thus comes to lie between the collenchymatous cells of the outer cortex and the cork cells of the bark. Certain of the collenchymatous cells in contact with the fungus are destroyed, but the amount of penetration of this tissue is always slight. The increase of thickness of the stroma is brought about mainly by the laying down of radially arranged cell rows on the side towards the bark, thus forcing the bark outwards. The cell walls in the outer region of the stroma then become dark and a more or less distinct palisade of short conidiophores forms on the convex surface. Eventually, the bark gives way to the pressure beneath and splits off from the centre outwards. On the dark stroma surface thus exposed, a profuse conidial formation is initiated which may continue for several weeks (Fig. 4).

The further development of the fungus stroma is affected by the formation of cork barriers in the host tissue. During July, cork barriers can be found beneath infections at the base of shoots of the current year, and thereafter the formation of barriers continues to spread upwards in the stem, following closely on the process of normal cork formation. A typical barrier is produced by the activity of a plate of phellogen cells which arise by the division of cells of the cortex. These phellogen cells are usually first seen below the centre of the stroma and they may arise either in the collenchymatous outer cortex or in the parenchymatous inner cortex. From this phellogen, layers of cork cells are cut off towards the exterior of the stem, with the result that all the host cells outside the barrier collapse and die (Fig. 4). The barrier continues to extend towards the margin of the stroma and may enclose it completely, forming a complete union with the normal bark. In this event the stroma withers and may be shed, together with the remains of the host tissue external to the cork barrier. Frequently, however, a stroma extending vigorously at the margins will outflank the barrier so that although the central mass of the stroma is cut off and dries up, small masses of mycelium remain unenclosed by the cork barrier. Occasionally, a further attempt at enclosure may be made by the shoot in the laying down of a second cork barrier nearer the shoot axis than the first—this is seen only towards the base of a shoot.

As infections may take place at any favourable period between June and September, it follows that a scabbed shoot examined in late summer or early autumn may simultaneously bear infections at different stages. In the young infections near the tip of the shoot, the fungus will not have penetrated farther than the epidermis and the general appearance will resemble that of a young infection on a leaf. Lower down the shoot the fungus will be in the form of a relatively thick stroma forming a definite protuberance with a spore-bearing surface bursting through the bark. Towards the base of the shoot the remains of exhausted stromata will occur as black withered masses. In this area, also, may be found the convex cork-protected scars marking the sites of pustules which, with the surrounding host tissue, have been completely cut off and shed.

With the cessation of growth of the shoots in the autumn, the development of cork barriers comes to an end until the following summer. The fungus, however, does not cease growth. The superficial infections near the tip of the shoot pass into the stroma stage, and elsewhere in the shoot, where cork barriers are present, the extent of invasion by the fungus is increased by the development of subsidiary pustules. These pustules may be formed from mycelial masses which were not enclosed on the formation of a cork barrier, or they may arise from a cork-encircled stroma as outgrowths which disrupt the barrier at its junction with the bark (Fig. 5). When the barrier is passed, the fungus extends vigorously under the bark around the original stroma and also sends back tongues of mycelium which invade the tissue immediately underlying the cork barrier. Occasionally a breach may be made in the central region of the barrier by the growth of a wedge of mycelium from the inner side of the original stroma (Fig. 6). In either event, the final result is the production of new stromata around and below the tissues infected in the previous summer and autumn (Fig. 5). The external appearance of a scab-infection at this stage is shown in Fig. 7.

The new extensions of fungus tissue remain covered until spring—the peripheral stromata being protected by the normal bark and the central stroma being below the cork barrier. Growth of the fungus continues slowly throughout the winter, accompanied by a gradual killing and digesting of those collenchyma cells which are in contact with the fungus mycelium.

During March and April the growth in thickness of the subsidiary stromata is accentuated, with the laying down of radially-arranged cell rows as observed in the summer stromata. Conidiophores are formed, as previously described, and if at any point there is a space between the conidiophores and the bark, conidia will be formed, although the bark is still unbroken. Eventually the bark gives way to the pressure of the pustule beneath, and is ruptured by a split usually running parallel with the axis of the shoot (Fig. 8). On the surface of the stroma thus exposed, conidial formation (if not previously started) begins in the central portion and spreads towards the margins. Conidia are usually produced from these pustules until about the end of May. This point is further dealt with in Section iii below.

During the latter half of May further cork barriers are laid down which partially or entirely cut off the subsidiary pustules. Considerable variations occur both in the place of origin and in the mode of development of these barriers, such differences being frequently observable even in neighbouring infections on the same shoot. Where the barrier arises in the outer cortex, a plate of meristematic tissue, two or three cells in depth, is formed by division of the collenchymatous cells, and from this the cork cells are cut off on the side towards the infection. In the parenchymatous inner cortex, a more extensive preliminary division of cells takes place and the cork is laid down on the abaxial face of a relatively deep plate of thin-walled tissue. Where a cork layer arises in the pericycle, the parenchymatous cells behave as in the inner cortex while the fibres occurring along the course of the barrier remain unchanged.

When secondary growth of the wood commences in late May or early June, the sloughing off of the infected tissues is accelerated by the increase in girth of the shoots. The tension thus set up not only causes the loosening and fall of the tissues cut off by the cork barriers, but also not infrequently brings about splitting of the cortical tissues before barrier formation is complete. In particular, splitting is liable to occur in the thin-walled tissue which is developed in the inner cortex prior to barrier formation. If healthy shoot tissue is thus exposed, the cell walls in contact with the air rapidly become suberized while a regular cork barrier is subsequently developed within.

It is common to find that the youngest extensions of the scab pustules are not cut off with the remainder of the infected tissue. During the summer months, however, these are almost all isolated by further barriers and abscinded. Only very rarely will any living portion of an infection persist on a shoot beyond the summer following that of its initiation. Generally speaking, infections are found only on shoots of the current and of the previous season.

(ii) *Conditions influencing the course of infection on the variety Lord Suffield.*

Natural infections with the apple scab fungus are brought about by conidia (or ascospores) which are carried in wind-blown rain. Conidia thus carried on to the terminal portion of developing shoots of the variety Lord Suffield are enmeshed in the covering of epidermal hairs. These hairs prevent the spores from being carried to the leeward side of the twig, with the result that infections of apple shoots are found predominantly on the side facing the prevailing rain-bringing wind. A count made at Long Ashton in the spring of 1931 on thirty-seven shoots of Lord Suffield taken at random gave a total of 638 infections on the S.W. side compared with 98 on the N.E. side.

The hairs have also the effect of preventing a large proportion of the spores from reaching the cuticle of the shoot proper. While they in this way reduce attack, it is also probable that the hairy covering hinders the drying of the shoot and thus favours the chances of infection by such spores as reach the shoot surface. No evidence has been obtained that infection takes place more frequently at the hair bases than at any other portion of the dermal tissues.

The necessity for continued moist conditions to ensure germination of the spores of the scab fungus is well known. While no exact investigations have been made of the water relations of spores germinating on the shoots, field observations have demonstrated that the correlation between wet periods and initiation of scab infections is as well marked for the shoots as for the leaves and fruits. Thus, the shoots formed in 1930 showed, when examined in spring 1931, abundant scab infections towards the tip, brought about in the wet August and September of the previous year.

When weather conditions are favourable, new infections may take place at any time during the elongation of the shoot, but only in the green apical region. The distance from the shoot tip at which a successful infection can be initiated is dependent on the rapidity with which the epidermis forms cork, and for this no general rule can be laid down. Cork formation in watershoots is relatively tardy, whereas in short spurs the epidermis develops cork almost as soon as formed. Any rapidly elongated shoot commonly shows delayed cork formation and on such shoots, which are recognized as being more susceptible to scab attack, infections may be initiated for a distance of two or three inches below the tip.

When the germ-tube of the fungus spore has penetrated the cuticle, the infection thus started may complete the full cycle described above or the course of infection may, by the activities of the host, be arrested at one of several stages. If the cuticle is penetrated at a point where cork cells are already completed, the fungus does not penetrate farther but remains as a thin, subcuticular plate which may form a few spores but is shed with the cuticle during the season of infection. If the fungus, however, reaches the phellogen it forms a stroma in this region on which numerous spores are produced. After a few weeks' existence this stroma will usually become more or less isolated by a cork barrier laid down in the cortical tissues. If the scab pustule is entirely included within the cork barrier it may fall from the twig during the season of infection or it may become withered during the winter and make no further growth. Only those stromata which are not fully enclosed when barrier formation ceases or which break through the barrier during the winter are able to provide subsidiary pustules which form the new spores in the spring. The number which thus complete the full cycle is a relatively small proportion of the original infections.

(iii) *The dissemination of spores from scabbed shoots of Lord Suffield.*

From a consideration of the life cycle of a shoot infection, it will be seen that spore production may take place from April until the autumn. On the new infections initiated during the summer, spores are first produced when the mycelium is forming a subcuticular plate—a type of fructification similar to that on the leaf. In older shoot infections, conidia are produced on the surface of stromata which had developed in the region of the phellogen and then split off the overlying bark (Fig. 4). These stromata are relatively thick pads of tissue which may continue to form new spores until approximately the end of September. Some of the latest-formed spores frequently remain on the surface throughout the winter, but tests made in November, 1930, showed that the spores on the pustules at that time would not germinate. During April, the subsidiary pustules, which had been forming during the winter around the original stromata, burst open the bark (Fig. 8) and thereafter continue to produce conidia during the spring and summer until the pustule is shed. Tests made during April and May show that the conidia then produced from the shoots are from 50 to 70 per cent viable.

The dissemination of conidia from the shoots takes place only when the pustules are wetted. A current of dry air directed on to a fruiting pustule will dislodge only very few conidia, but a fine spray will quickly remove all that are mature. Under natural conditions, the conidia are dispersed in wind-blown rain, and it is observed that the conditions required for dissemination of the conidia occur much more frequently than those required for their germination. Some preliminary records relating to the dissemination of conidia during the spring months have already been given (Marsh, 1931). Owing to the importance of the spring-produced spores in bringing about the initial infections of the season, further studies of spore dispersal were made during April and May, 1931. The block of seven-year-old trees in the Long Ashton plantations used for observations is illustrated in Diagram 1.

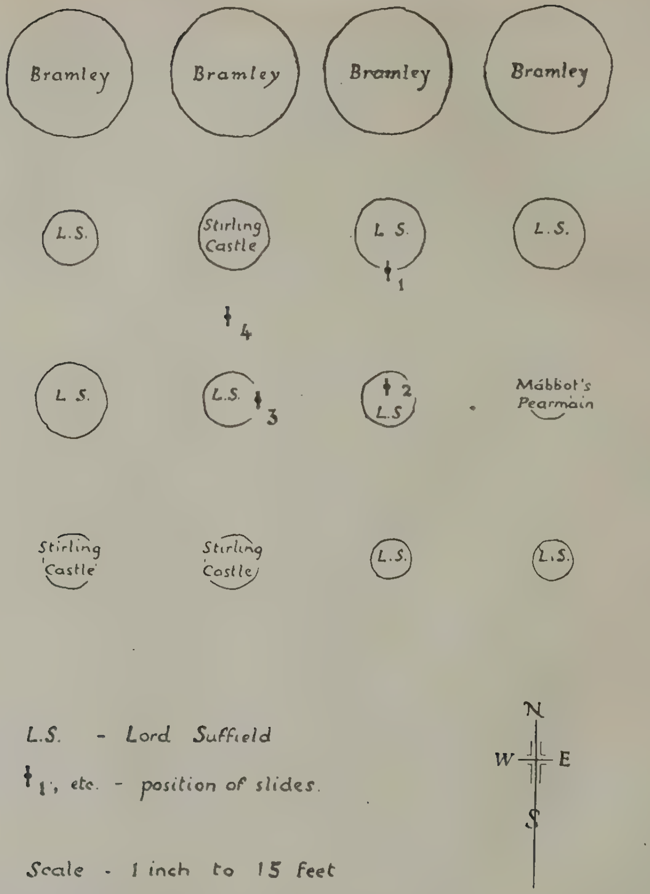
Bramley
Bramley
Bramley
Bramley
L.S.
Stirling Castle
L. S.
1
L.S.
4
L. S.
L.S.
3
2
L.S
Mábbot's Pearmain
Stirling Castle
Stirling Castle
L.S.
L.S.
L.S. - Lord Suffield
1, etc. - position of slides.
Scale - 1 inch to 15 feet
N
W
E
S

DIAGRAM I.

Plan of Section of Plot used for Spore Trapping Experiments in Spring, 1931.

In this block, the trees of the variety Lord Suffield carried abundant scabbed wood: the shoots of the remaining varieties were practically free from scab. Vaselined slides (3 in. by 1 in.) were hung, with their long axes N. to S., in the following positions:—

Slide 1. 2 ft. 6 in. above soil level: 2 ft. 6 in. S. from centre of tree. (No branches of same tree either E. or W. of slide.)

Slide 2. 3 ft. above soil level: 1 ft. 6 in. N. from centre of tree. (Other branches of same tree E. and W. of slide.)

Slide 3. 3 ft. above soil level: 2 ft. E. from centre of tree. (All rest of tree to W. of slide.)

Slide 4. In alley, 2 ft. above soil level. (Nearest scabbed shoots 5 ft. S.)

The slides were put up as soon as splitting of the bark over the subsidiary scab infections was observed, on April 7th, 1931. The blossom buds of Lord Suffield were then at the "burst" stage (see Diagram 2). The four slides were collected and examined on April 16th, the records being as follows :—

Slides exposed, April 7th-16th (9 *days*).

Slide 1. On 1 sq. in. W. side—175 conidia.
,, ,, E. ,, —No record.
Slide 2. ,, ,, W. ,, —404 conidia.
,, ,, E. ,, — 37 conidia.
Slide 3. ,, ,, W. ,, —440 conidia.
,, ,, E. ,, —No record.
Slide 4. ,, ,, W. ,, — 99 conidia.
,, ,, E. ,, — 0 conidia.

Fresh slides were placed in the same positions at 5 p.m. on April 16th. At 12 noon on April 17th, Slide 3 was removed for examination and replaced by a fresh slide.

Slide exposed April 16th-17th (19 *hours*).

Slide 3. On 1 sq. in. W. side—313 conidia.
,, ,, E. ,, — 2 conidia.

The slide put up on April 17th was taken for examination after a further twenty-four hours and a fresh slide substituted.

Slide exposed April 17th-18th (24 *hours*).

Slide 3. On 1 sq. in. W. side—5 conidia.
,, ,, E. ,, —0 conidia.

(The contrast between these figures and those for the previous exposure in the same position is attributed to the fact that the wind was N.W., obliquely on to the face of the slide, during the former exposure, but then changed to N., blowing end on to the slide, during April 17th-18th.)

All the slides were again collected and examined on April 27th, the results being :—

Slide exposed April 18th-27th (9 days).

Slide 3. On 1 sq. in. W. side—214 conidia.
,, ,, E. ,, —No record.

Slides exposed April 16th-27th (11 days).

Slide 1. On 1 sq. in. W. side— 54 conidia.
,, ,, E. ,, — 36 conidia.
Slide 2. ,, ,, W. ,, —430 conidia.
,, ,, E. ,, —No record.
Slide 4. ,, ,, W. ,, — 12 conidia.
,, ,, E. ,, — 12 conidia.

Fresh slides 1, 2 and 3 were put in position on April 28th and Slide 3 was examined twenty-two hours later, the result being :

Slide exposed April 28th-29th (22 hours).

Slide 3. On 1 sq. in. W. side—12 conidia.
,, ,, E. ,, — 0 conidia.

Another Slide 3 was substituted on April 29th and the final examination of all the slides made on May 11th, with the following result :

Slides exposed April 28th-May 11th (13 days).

Slide 1. On 1 sq. in. W. side— 86 conidia.
,, ,, E. ,, —114 conidia.
Slide 2. ,, ,, W. ,, —104 conidia.
,, ,, E. ,, — 73 conidia.
Slide 3. ,, ,, W. ,, —106 conidia.
,, ,, E. ,, — 24 conidia.

The complete results are given in summarized form on Diagram 2, which also gives the rainfall and wind records for the period April 5th-May 11th. Reference to this diagram and to Diagram 1 will suggest that much of the variation in the spore counts may be attributed to the placing of the slides in relation to the infected trees and to the direction of the wind during wet periods. Apart from this, however, there are indications that the average number of spores shed per day decreased towards the end of the period of observation, and also that the number of spores reaching Slide 4, five feet from an infected tree, was much lower than that reaching any of the slides actually attached to infected trees, during the same period.

(iv) *Scab attack on shoots of varieties other than Lord Suffield.*

Scab attack has not yet been recorded on the shoots of certain varieties of apple such as Bramley's Seedling. In all varieties susceptible to shoot infection, however, it appears that the general process of development of the scab fungus on the shoots is as described for the variety Lord Suffield. The differences which exist are mainly differences of degree and may be exemplified by brief descriptions of the course of scab attack on the shoots of three commercial varieties. Of these varieties, Lane's Prince Albert is generally little subject to scab attack on shoots, Worcester Pearmain shoots are commonly attacked, and on Cox's Orange Pippin scabbed wood is of widespread occurrence.

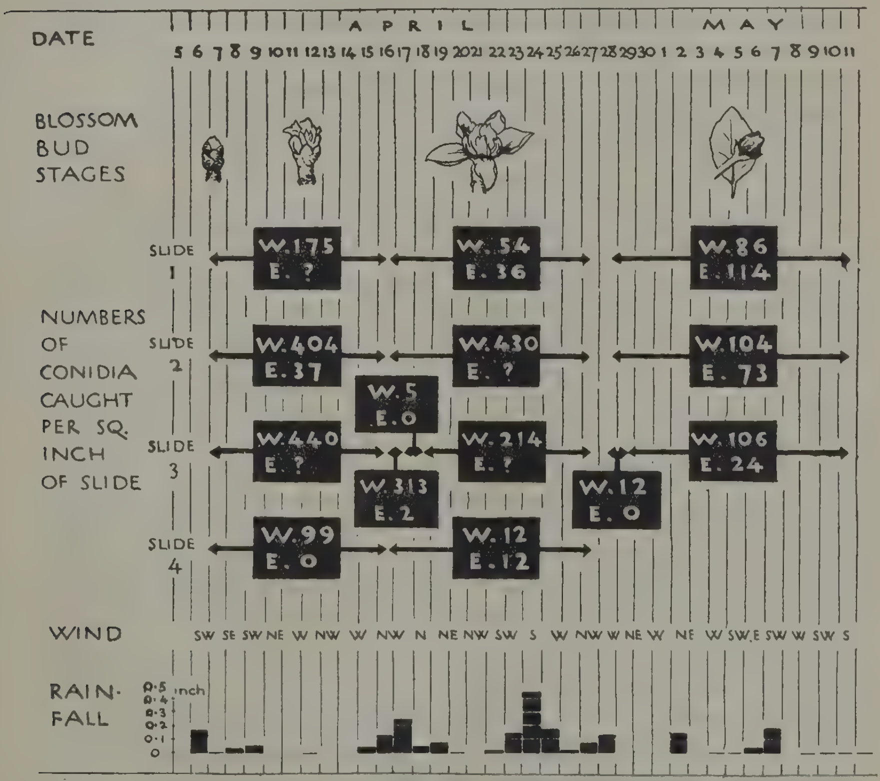

DIAGRAM 2.

Results of Spore Trapping Experiments in Spring, 1931. For further details see text.

Lane's Prince Albert.—On this variety infected shoots are relatively infrequent and the scab pustules occurring on any one shoot are few. In the new shoots developing during the summer, normal cork formation starts very close to the tip, with the result that the period during which any portion of shoot is covered only by the vulnerable epidermis is short. Of the infections which take place, many are isolated by cork layers when they are still relatively young, and most of the remainder become cut off by the autumn. Where the infections succeed in forming subsidiary pustules, these take the form described on the shoots of Lord Suffield but are generally on a smaller scale. The cork barriers which eventually enclose the subsidiary pustules arise either in the inner or the outer cortex, and the scars left by the abscinded pustules are usually shallow. The laceration of the bark in this variety, commonly known as " rough bark," appears to bear no relation to scab attack.

Worcester Pearmain.—Infected shoots of Worcester Pearmain are of common occurrence following a wet season. In a rainy summer, numerous small infections arise on the shoots but these remain shallow and are almost all enclosed by cork barriers before the winter. In the early winter months, shoots are frequently found thickly studded with small protuberances, caused by the forcing up of the bark by growth of the cells of the inner cortex. Enclosing these proliferated cells, a cork barrier is usually seen and often, though not invariably, scab mycelium can be found in the neighbouring cells of the outer cortex. It appears that in this variety a small infection may give rise to far-reaching disturbances in the cortex towards the end of the growing season. During the late winter and spring, subsidiary pustules arise as previously described but these pustules are small and frequently occur only at one or two points around the circumference of the original infection. The final cutting-off of the subsidiary pustules is brought about by barriers arising in the cortex.

Cox's Orange Pippin.—In this variety, shoot infection is widespread and intense. The course of infection shows practically no difference from that observed in Lord Suffield although the production of bark protuberances, as described for Worcester Pearmain, has been noted. During the summer the scab fungus readily infects the new shoots, forming thick stromata which are frequently imperfectly cut off by the end of the growing season. Conspicuous subsidiary pustules are formed during the winter, partially or completely surrounding the original infection. When these pustules are cut off in May and June the cork barriers frequently originate in the pericycle and very considerable disruption of the cortex results. In consequence, any two-year-old wood of Cox which has experienced a scab attack shows pronounced scarring.

DISCUSSION.

The type of infection produced by the scab fungus on an apple shoot differs markedly from the type produced on fruit or leaves. On the leaves, the infection is strictly subcuticular, the fungus not penetrating the epidermal cells until the leaf becomes moribund. On the fruit, the epidermal and sub-epidermal cells may be penetrated and a thin stroma produced, but the infection remains purely external. By comparison, the fungus exhibits a more intense form of parasitism on the shoots—the ability to penetrate below the surface of the host tissues.

At all stages in the development of a scab infection on a shoot this ability to penetrate follows on the production of a meristematic layer in the host tissue. Such layers are of infrequent occurrence in the apple leaf or fruit ; the scab fungus is there in contact with an epidermis which is not meristematic. Professor J. H. Priestley* remarks on this point as follows : " There is one difference in the epidermal conditions in the leaf and in the young stem, to which I have often had my attention drawn. In the leaf this region is relatively dry. In the stem it is often flushed with water containing substances in solution. That is why the cuticle continues to grow thicker in the stem for a long period and why, in walls below the cuticle, we often find substances deposited—just as they are left on the beach by the tide. It is also the reason why in the stem we get later the formation of epidermal cork, whilst in the foliage leaf such a phenomenon practically never occurs. You will readily understand that to keep the meristem of the cork nourished much substance must be brought to it in solution. Now I take it these same substances may well be available for the growth of the fungus in the stem and not available for its growth in the leaf."

The epidermis of the shoot thus forms a much more congenial environment for the scab fungus than that of the leaf. In the shoot, the fungus, having reached the underside of the cuticle, rapidly forms a pad of pseudoparenchymatous tissue and brings about the breakdown of the epidermal cells. This invasion continues into the surrounding epidermal cells and is not checked when the epidermis becomes the phellogen ; with the result that the growth of the fungus is directed beneath the bark. The suberized cells of the bark and the thick-walled cells of the outer cortex offer considerable resistance to the attack of the mycelium, so that, while the invasion continues to spread tangentially, it remains during the summer confined radially by the bark tissues above and the collenchyma below.

During the winter the growth between the collenchyma and the bark continues, to form the subsidiary pustules ; from these a deeper penetration of the fungus takes place along the line of the phellogen from which the first cork barrier arose (Figs. 5 and 8). Protection is thus assured during the winter for all the subsidiary pustules, which are the only portions of the fungus tissue of importance in spring spore production.

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* in litt.

With the recommencement of phellogen growth in June it might be expected that the fungus would continue its tangential spread under the bark and once again send outgrowths beneath the new cork barriers forming under the subsidiary pustules. If this process took place the infection of the adjacent tissues would be assured for another year. However, the abscission of infected tissue in June is a much more rapid process than the gradual barrier formation of the previous late summer and autumn. The increase in girth of the stem supplements the effect of the new cork barriers in causing the sudden splitting off of relatively large patches of cortex, including, in most instances, the whole of the infected tissue. In varieties such as Lord Suffield and Cox's Orange Pippin this disruption may extend down to the pericycle and cause drying out of the tissues owing to the interruption of the cork barrier by the bast fibres. In the majority of varieties, however, the cortex only is affected and the scabbed tissue is shed without permanent injury to the shoot.

From the economic standpoint, the direct damage caused by scab to the shoots is slight ; the importance of scabbed wood lies in its effect on spring infection of the leaves. Spore dissemination from scabbed shoots starts at least as soon as leaf rudiments are exposed, and continues beyond the period when the new leaves themselves start discharging spores. More records are required before any opinion can be given concerning the relative importance of scabbed shoots and of overwintered leaves in initiating spring outbreaks of scab in this country ; there are varieties not susceptible to shoot attack in which, obviously, overwintered leaves are the only possible source of infection. Exposures of vaselined slides in two blocks of Bramley's Seedling in Kent from April 25th to May 3rd, 1932, showed that, while no conidia were detected, small numbers of ascospores were present in the air during this period.* On the other hand, where scabbed wood exists, the records given above (see Diagram 2) demonstrate that scabbed shoots are potential sources of heavy infection during April and May.

Touching the question of spraying specifically to kill scab pustules on shoots, it would appear unlikely that any successful method of direct attack could be devised. The young infections on the wood are at first protected by the cuticle ; by the time the fungus breaks through the cuticle it is already many cells in thickness, and the margin of the fungus tissue rapidly becomes esconced beneath the newly-formed bark. When the fungus reaches the stroma stage it is doubtful whether any summer spraying could do more than kill the outer layer of the exposed portions of the stromata: meanwhile the basal portion and the peripheral extensions beneath the bark would remain unharmed. Throughout the winter, the only parts of the scab fungus that are exposed are the exhausted remains of the summer stromata; meanwhile, the subsidiary pustules which will produce spores in the spring are entirely covered. Spraying the scabbed shoots in the spring might check spore formation on the open pustules, but spore formation has been noted on shoots which had had three sprayings with Bordeaux mixture in April and May, so the arrest of spore production is not permanent.

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* For assistance in carrying out these tests, I am much indebted to Messrs. W. G. Kent and M. H. Moore, of the East Malling Research Station, and Mr. E. J. Wilson, of Stone Street, Kent.

The control of scab in shoots can best be undertaken as part of the general process of scab control on the tree. A series of protective sprayings preventing the establishment of scab on the leaves and fruit will at the same time preserve the developing shoots from infection. As the activity of scab pustules very rarely persists on two-year-old wood, the prevention of new shoot infections throughout the summer and autumn will completely free the tree from scab-infected wood in the succeeding spring.

SUMMARY.

An account is given of the mode of infection and growth of the scab fungus (*Venturia inæqualis*) on apple shoots of the variety Lord Suffield.

The progress of penetration of the tissues, the reaction of the host and the method of abscission of the diseased areas are described.

Modifications of the course of infection within the variety Lord Suffield and in certain other varieties are recorded.

Results are given of spore-trapping experiments made in the vicinity of scabbed shoots. As a result of such experiments the importance of scabbed shoots as potential sources of infection in April and May is demonstrated.

The difficulties of killing scab pustules on shoots by direct spraying are discussed.

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EXPLANATION OF FIGURES.

FIG. 1.

L.S. six-day-old infection on shoot of Lord Suffield, inoculated 28·5·31, fixed 3·6·31. The fungus has formed a pseudoparenchymatous mass of tissue below the cuticle and is beginning to invade the epidermal cells. Cork formation by the epidermis has not yet started. (Stained iron alum-haematoxylin.)

FIG. 2.

T.S. infection approximately three weeks old on shoot of Lord Suffield. Normal cork formation did not occur until the pseudoparenchyma had made extensive subcuticular growth. The fungus has forced off the cuticle and is producing spores. Cells in the cortex below the fungus tissue are dividing preparatory to forming a cork barrier. (Stained lacto-phenol-cotton blue.)

FIG. 3.

L.S. twelve-day-old infection on shoot of Lord Suffield, inoculated 16·7·31, fixed 28·7·31. The phellogen formed from the epidermis has cut off 3-4 layers of cork cells since infection commenced. The sub-cuticular growth of the fungus was speedily arrested, but the invasion of the phellogen tissue beneath the cork proceeds vigorously. (Stained iron alum-haematoxylin.)

FIG. 4.

L.S. ½ inch from tip of Lord Suffield shoot 23·10·31. The fungus forms a stroma about 100μ thick, spreading peripherally beneath the bark. On the exterior of the stroma a palisade of conidiophores from which conidia are abstricted ; at the base, the remains of partially-digested cortical cells. Below this, a cork barrier with its underlying phellogen, formed from the collenchyma cells of the cortex. Note on the right a small patch of fungus tissue not enclosed by the cork barrier. (Unstained.)

FIG. 5.

Diagram of L.S. Lord Suffield shoot cut 3·12·30. Subsidiary pustules have developed on either side of the original stroma, and a tongue of mycelium is starting to grow beneath the cork barrier, following the line of the phellogen. The region shown in black between the stroma and the cork barrier is occupied by dead cortical cells. (Stained cotton blue-Sudan III.)

FIG. 6.

T.S. Lord Suffield shoot cut 3·12·30. The developing stroma has broken directly through the cork barrier. (Stained lacto-phenol-cotton blue.)

FIG. 7.

Shoot of Lord Suffield 19·1·32 showing external appearance of scab infections. The central blackened stroma is bordered by a ring of raised bark covering the subsidiary pustules.

FIG. 8.

T.S. shoot of Lord Suffield 18·4·31. In the centre are the blackened remains of the 1930 stroma, below this are dead cortical cells and then a cork layer. One subsidiary pustule lies below the cork layer, the other two are on either side (*cf.* Fig. 7). The right hand subsidiary pustule has burst through the bark and is forming spores. No cork barrier formation has yet started below the subsidiary pustules. (Stained Sudan III.)

(*Received* 18/4/32.)

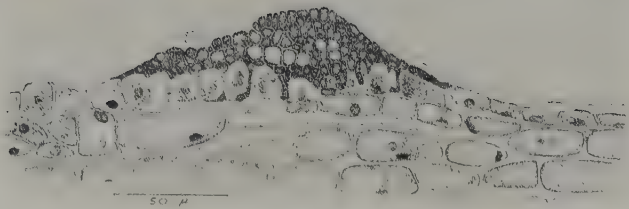


FIG. 1.

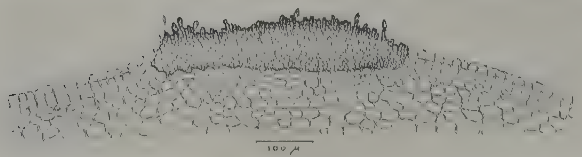


FIG. 2.

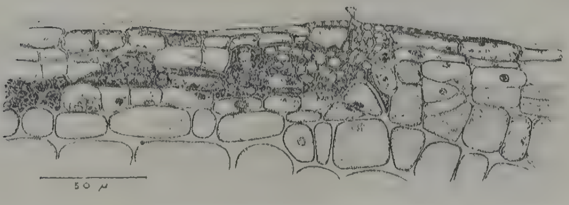


FIG. 3.

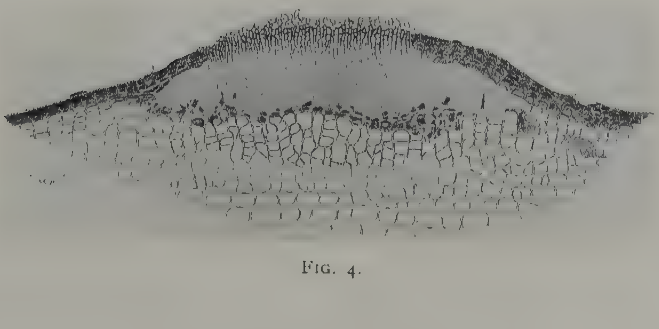
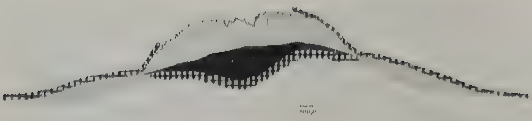


FIG. 4.



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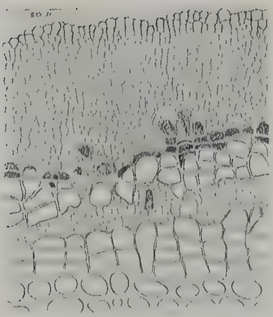

FIG. 6.

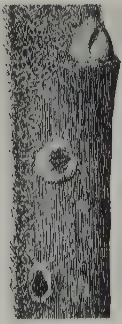

FIG. 7

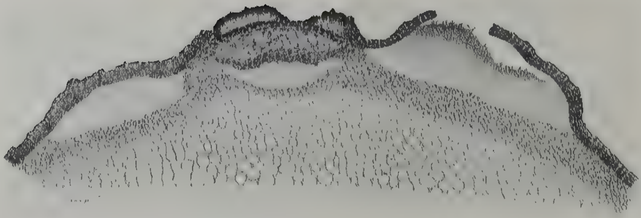

FIG. 8.

MANURIAL EXPERIMENTS WITH HOPS IN POT CULTURE.

By F. H. Beard,
East Malling Research Station.

In the spring of 1927 it was decided to lay down a pot culture experiment with hops on similar lines to those adopted for fruit trees by Wallace at Long Ashton (15, 16), with the object of obtaining, if possible, symptoms of manurial deficiencies, in order to recognize them later under field conditions.

Field Experiments on the Manuring of Hops.

A field manurial trial with the variety Tutsham was laid down at East Malling in 1922 (1) to test (a) various organic manures as substitutes for dung, (b) the value of different forms of phosphatic manures, (c) the effect of various quantities of potash. The trials were discontinued in 1927, the results being obscured by the ravages of the " mosaic " disease. No special foliage characters were noted on any plots except those receiving no potash on which the large leaves lost their green colour earlier, becoming purplish and falling before those on the plots receiving potash (1).

Field experiments on the question of manurial deficiencies have been carried out for some years by Burgess of the South-Eastern Agricultural College, Wye, at Chilham and Horsmonden (3, 4). The treatments on these plots are complete (with dung) ; complete artificials ; no potash ; no phosphates ; no nitrogen ; and control (unmanured). The writer visited the plots at Chilham in 1930 and it was possible to pick out readily the plots by sight so closely did the symptoms resemble those of the comparable pot cultures.

On the Chilham plots the omission of phosphates has only recently affected the yield, similarly at Horsmonden the omission of potash gave no reduction in yield in the earlier years (3).

General Plan of Experiment.

A small preliminary experiment was started in March, 1927, with the object of establishing a satisfactory technique.

Twenty-one rooted sets (one year old) of the seedling variety M20 (hop of unknown origin x English male hop) were each planted in an 18 in. unglazed pot filled with a weighed amount of a pure white sand of local origin. All the drainage holes in the pots were sealed except one in the front of each pot, which was fitted with rubber bung and glass tube plugged with glass wool, to prevent the escape of the sand.

A trench was dug out and recesses to hold one pot each were cut out on either side, boards were then placed in front of the pots to keep them in position. The tops of the pots were fitted with wooden gable roofs to give protection from rain and prevent excessive evaporation. The bines were trained up wirework of the " Butcher " system. The solutions used were similar to those used by Wallace at Long Ashton (15, 16).

COMPLETE NUTRIENT SOLUTION.

Sodium nitrate	5·0	gms.
Potassium nitrate	2·0	,,
Potassium dihydrogen phosphate	1·0	gm.
Calcium sulphate	1·0	,,
Magnesium sulphate	1·0	,,
Sodium chloride	1·0	,,
Ferric chloride	0·4	,,
Rain water to	1	litre.

One litre of solution to be diluted with 9 litres of rain water prior to application.

The other solutions were derived from the above solution by substituting sodium for any base-forming element omitted and the sulphate radical, where an acid radical was omitted.

TREATMENTS.

Series A. Complete nutrient solution.
,, B. Nitrogen omitted.
,, C. Potassium omitted.
,, D. Phosphorus omitted.
,, E. Calcium omitted.
,, F. Magnesium omitted.
,, G. Rain water only.

The pots were leached fortnightly with rain water. There were three plants in each treatment except in the complete nutrient series, where one " set " failed to grow.

SUMMARY OF OBSERVATIONS.

During the first season, definite foliage characters developed in only three treatments and bine growth varied considerably between plants in the same treatment, due, no doubt, to the fact that the plants were to a large extent drawing on the food supply stored in their fleshy rootstock.

The leaves of plants receiving no nitrogen and rain water only were of a paler green than those of plants in the other series. The plants receiving no magnesium developed marginal scorching and spotting towards the end of July.

In the second season the effect of the treatments was more marked and the growth of plants under the same treatments was more uniform. It was possible readily to distinguish those plants receiving no phosphoric acid on account of their stunted growth and small down-curved leaves of a dull dark green colour.

All the plants made much poorer growth than those under field conditions and there was considerable scorching, the latter being probably due to the difficulty of obtaining satisfactory drainage with the very fine sand used. At the end of 1928 the plants were lifted and the rootstocks weighed.

It is not necessary here to deal fully with the results of this earlier experiment as the results were strikingly confirmed by the main experiment, but a brief note on the plants under each treatment in the second season is given below.

Series A. (*Complete.*)

The second plant in this series failed to grow in the spring (possibly due to disease). The plants appeared healthy apart from scorching and yellowing of lower leaves. This series came second for bine growth. The root system was large and healthy. There was a fair crop of well developed cones.

Series B. (*No nitrogen.*)

The growth was stunted and the leaves were very small and pale green. There was very little scorching. The rootstock was very poorly developed, having increased less than 1 oz. in weight since planting. The plants failed to crop.

Series C. (*No potassium.*)

The plants appeared healthy apart from scorching on lower leaves. Shoot growth was good. The root system was slightly less well developed than in series A. The crop was equal to that of series A.

Series D. (*No phosphorus.*)

Plants in this series were stunted, with small down-curved, dull bronzed green leaves ; scorching occurred on lower leaves. Growth of bine and roots was only slightly greater than that of the no-nitrogen and rain water only series.

The plants failed to crop.

Series E. (*No calcium.*)

There was more scorching and yellowing of leaves than in series A. The plants were equal to the complete nutrient series A in growth, root development and cropping.

TABLE I.

Series.	Treatment.	1927.				1928.			Notes.
		No. of plants.	Average weight of sets.	Average total length of bine.	Crop* 1927.	Average total length of bine.	Average weight of rootstock.	Crop* 1928.	
			gm.	cm.		cm.	gm.		
A.	Complete Nutrient Solution	2	71	890	Good	1021	879	Good	Healthy; slight scorching on lower leaves.
B.	Nitrogen omitted	3	77	338	A few cones	146	93	Nil.	Leaves small and pale green.
C.	Potassium omitted	3	63	559	Good	891	320	Good	Rather more scorching than series A.
D.	Phosphorus omitted	3	65	485	Small	379	142	Nil.	Leaves small and of a dull dark green colour.
E.	Calcium omitted	3	71	919	Good	879	529	Good	Rather more scorching than in series A.
F.	Magnesium omitted ..	3	71	681	Good	1236	348	Good	Angular spotting and scorching on leaves.
G.	Rain water only	3	65	330	A few cones	168	85	Nil.	Similar to series B.

* Crop compared with that of complete series.

Series F. (*No magnesium.*)

This series appeared very healthy at the beginning of the season, but by about the third week in July typical angular spotting and scorching of the lower leaves appeared; this scorching worked gradually up the bine and caused the leaves to fall prematurely. The root system was only moderate. The crop was equal to that of series A.

Series G. (*Rain water only.*)

The plants in this series were not distinguishable in any respect from those of series B (no-nitrogen).

Table I shows the average growth in each series for the two seasons.

After reviewing the information so far obtained it was decided to lay down a more extensive experiment embodying the necessary alterations in technique.

MAIN EXPERIMENT.

The seedling variety L21 (Tolhurst × English male hop) was selected for the experiment as an ample supply of clone material was available.

This variety also possesses the advantages of being immune to "mosaic" disease and very resistant to the Hop Downy Mildew (*Pseudoperonospora humuli*). It is rather a weak grower even under optimum conditions in the field.

In March, 1929, forty-two one year old rooted sets of as uniform size as possible were selected and planted in 18 in. pots filled with a weighed amount (140 lb.) of pure Bedfordshire silver sand. All drainage holes were sealed except one in front of the pot which was fitted with copper gauze to prevent the escape of the sand, whilst allowing free drainage of surplus water.

A few spare sets were planted in smaller pots for transplanting in case of failure to grow on the part of any of the sets in the experiment, but it was not necessary to make use of these plants.

The pots were then plunged in the manner already described in the earlier experiment. The treatments were identical with those of the preliminary experiment. Owing to the solutions used having a higher potash-nitrogen ratio than that usually recommended for hops, it was decided in 1931 to study the effect of watering half the plants in each treatment (except series B and G) with solutions containing a higher proportion of nitrogen.

The following records were taken :—

(a) Types of foliage.
(b) Length of bine.
(c) Weight of bine.
(d) Weight of rootstock at lifting, December, 1931.
(e) Notes on cropping.

Table II.

Series A and G. Weight of Sets at planting and Shoot Growth in 1929 *and* 1930.

Treatment.	1929.		1930.
	Weight of set at planting.	Length of bine.	Length of bine.
	gm.	cm.	cm.
Series A.	57	450	1322
Complete nutrient solution ..	57	465	1250
	71	858	1306
	42	374	1247
	42	346	1220
	71	488	1264
Mean	58	498	1268
Series G.	57	205	251
Rain water only	85	373	249
	71	382	210
	42	251	185
	99	558	338
	99	571	302
Mean	76	390	256

No attempt was made to regulate the numbers of bines trained up for the first two seasons, but in 1931 six bines per plant were trained up, the remainder being pulled out.

The plants were attacked each season by the Hop-Damson Aphis (*Phorodon humuli*) which made it necessary to spray the plants once with nicotine and soft soap solution. The spray was applied with a knapsack machine as soon as the aphis appeared, so that the plants were not injured by the attack. The infestation, as far as could be judged, appeared to be of uniform intensity on all the plants.

Results.

During the first season the plants showed little response to the treatments except in the case of series B and G (no-nitrogen, rain water only) which had pale green leaves. There was considerable variation in growth between plants in the same series. The length of bine made by individual plants was considerably affected by the size of the set at planting, due to the relatively large supplies of food material stored in the rootstock.

Table II gives the weight of the sets at the time of planting and the bine growth for the first and second seasons of the plants receiving the complete nutrient solution and of those receiving rain water only. On referring to this table it will be seen that the growth of plants in the complete nutrient series in 1929 varied from 346 cm. to 858 cm., the average being 498 cm. whilst the growth of the plants receiving rain water only varied from 205 cm. to 571 cm., the average being 390 cm. In three cases plants in the latter series made more growth than certain plants in the complete nutrient series.

In the second season variation between plants under the same treatment was largely reduced by the effect of the treatments. Plants in the complete nutrient series varied from 1,220 cm. to 1,322 cm. in length of bine with an average of 1,269 cm., whilst those in series G (rain water) varied from 185 cm. to 338 cm. in length, with an average of 256 cm. The greater variation in growth from plant to plant in this series even in the second season was probably accounted for by the fact that the plants were entirely dependent on the food material stored in their roots.

In 1931 the differences in growth between plants under the same treatment was further reduced, whilst the no-nitrogen and rain water only series still remained the most variable.

In 1931 data was obtained relating to the number of shoots produced per plant prior to pulling to reduce the number to six bines in each case.

The results are given in Table III.

TABLE III.

Series	Treatment.	Average number of shoots per plant.
A	Complete Solution	24
B	Nitrogen omitted	8
C	Potassium omitted	21
D	Phosphorus omitted	10
E	Calcium omitted	26
F	Magnesium omitted	21
G	Rain water only	6

The detailed observations made on the plants may be summarized as follows:

Series A. (Complete nutrient solution.)

The foliage of the plants in this series was a healthy green colour and well developed, but by about the middle of July scorching appeared on the lower leaves which dropped prematurely. The rather poor growth of the plants in comparison with those in the field may possibly be due to the restricted root room afforded by the pots.

The amount of bine produced was good when compared with that of plants in the other treatments (Plate I).

This series came first in length of bine produced in 1931 and second in the two previous seasons. It was second in order of weight of bine.

The root systems were large and well developed, with plenty of fibre, and the dormant buds on rootstock well developed (Plate III).

The plants carried a relatively good crop of well developed cones.

Increasing the amount of nitrogen in the solution failed to give any very striking results ; there was rather more scorching, and the weight of bine was increased to a slight extent. The most marked and unexpected effect was an increase in the weight of the rootstock.

Series B. (*Nitrogen omitted.*)

The leaves of these plants were very small and pale green in colour ; scorching was practically absent. Growth was very poor and similar to that of series G (rain water only) (Plate I).

This series came seventh in order of bine weight. Cropping was poor in 1929 and almost nil in the two subsequent seasons (a few cones on one or two plants).

There was very little root growth, the roots being nearly all old and black, and the buds at the " crown " poorly developed (Plate III).

Series C. (*Potassium omitted.*)

Until 1931 the foliage was not greatly different from that of series A, but there was slightly more scorching. In 1931 the leaves were paler than those of series A, bronzing and severe scorching occurred at the end of August (Plate II).

Bine growth was good, being only slightly less than that of the complete nutrient series (Plate I). The bines remained green and sappy longer after leaf fall in the autumn than any other series and this caused the plants to have the heaviest weighing bine (Table IV).

Root growth was moderate, with plenty of fibre (Plate III). The crop was equal to that of series A in 1929 and 1930, but in 1931 the cones were not so well developed.

The addition of extra nitrogen had a very marked effect on the plants in this series. Severe scorching at the tip of the bine appeared at the middle of August and spread downwards (exactly the reverse of plants receiving smaller nitrogen ration).

The weight of bine was slightly increased.

Cropping was poor and the cones were badly developed.

The weight of rootstock was considerably greater than that of the plants receiving the normal solution.

Series D. (*Phosphorus omitted.*)

Plants in this series failed to show any marked foliage characters until the second season when a very definite leaf type appeared. The leaves were very small, downcurved, and of a dull dark green colour. Plants under this treatment could always be readily identified on sight on account of their very marked leaf character (Plate II). Growth was poor, being only slightly better than series B and C (no-nitrogen ; rain water only) (Plate I).

There was a poor crop in the first season and nil in the two subsequent years.

Root development was very poor, being slightly better than series B and G, buds on " crown " being poorly developed. All the roots were old and black ; there were no young roots of the current season's growth (Plate III).

The addition of an extra amount of nitrogen to the nutrient solution made no apparent difference in any respect.

Series E. (*Calcium omitted.*)

The leaves of plants under this treatment were rather larger than those of series A. Marginal scorching was present on the lower leaves which became yellow and dropped prematurely (Plate II). Growth in this series was good, being superior to series A in the two earlier seasons and coming only slightly below it in 1931.

A good crop was carried in each season. The root system was large and well developed, being equal to that of series A, with plump buds on " crown " (Plate III).

The plants receiving a higher proportion of nitrogen gave similar results except that the rootstocks were heavier in weight.

Series F. (*Magnesium omitted.*)

Plants under this treatment appeared very healthy in appearance in the early part of the season, but about the middle of July typical angular spotting and scorching occurred around the margins and between the veins on the lower leaves (Plate II) ; these symptoms quickly spread upwards, the affected leaves rapidly withering and falling off. This spotting and scorching became more severe each successive season and was associated with the formation of many laterals on the lower part of the bine. Growth in this series was good.

These plants bore a good crop in 1929 and 1930 but in 1931 there were a large number of cones but these failed to develop properly, probably owing to the fact that by the end of August nearly all the leaves had dropped.

The root system was good and there was plenty of fibre (Plate III), but the dormant buds on the " crown " were badly developed.

Plants receiving extra nitrogen showed similar symptoms, the scorching being rather more severe. There was no significant variation in growth or weight of bine and rootstock.

Series G. (*Rain water only.*)

Plants in this series were indistinguishable in all respects from series B (no-nitrogen) (Plate I).

TABLE IV.

Summary of Growth, 1929-1931.

Series.	Treatment.	Season 1929.		Season 1930.			Season 1931.				Remarks.
		No. of plants.	Average total length of bine.	No. of plants.	Average total length of bine.	Average weight of bine.	No. of plants.	Average total length of bine.	Average weight of bine.	Average weight of root-stock.	
			cm.		cm.	gm.		cm.	gm.	gm.	
A.	Complete nutrient solution	6	498	6	1268	71	3	1529	88	728	Healthy apart from slight scorching on lower leaves, crop good.
A1.	Ditto + extra nitrogen	—	—	—	—	—	3	1593	102	930	
B.	Nitrogen omitted	6	344	6	347	11	6	332	8	205	Leaves small, pale green. Crop nil.
C.	Potassium omitted	6	428	5	1281	112	2	1435	110	498	Slight scorching. Crop good.
C1.	Ditto + extra nitrogen	—	—	—	—	—	3	1297	132	780	Severe scorching. Cones failed to develop.
D.	Phosphorus omitted.	6	460	6	494	16	3	524	11	288	Leaves dull dark green.
D1.	Ditto + extra nitrogen	—	—	—	—	—	3	451	9	297	Crop nil.
E.	Calcium omitted	6	528	5	1335	67	3	1411	87	761	Healthy apart from marginal scorching on lower leaves
E1.	Ditto + extra nitrogen	—	—	—	—	—	3	1442	90	937	
F.	Magnesium omitted ..	6	404	5	1299	65	3	1468	78	708	Severe angular spotting on leaves, premature leaf fall. Crop failed to develop in 1931.
F1.	Ditto + extra nitrogen	—	—	—	—	—	3	1572	77	638	
G.	Rain water only ..	6	390	6	256	8	6	275	8	206	Similar to series B.

Table IV gives the average length and weight of bine for the three seasons and the average weight of rootstock at lifting. It will be seen that series A, C, E and F all made almost equally good growth.

In weight of bine, series C was significantly the heaviest. Series A (complete solution), E (no calcium) and F (no magnesium) do not differ significantly from each other, whilst series B (no nitrogen), G (rain water) and D (no phosphorus) are also alike in weight.

Root-Shoot Ratio.

As the relationship between root and shoot growth under varying conditions is now receiving attention, the following table giving the root-shoot ratio of the plants under the several treatments is included in this paper.

It will be noticed that in the case of plants receiving no nitrogen, no phosphoric acid or rain water only, the treatments reduced the weight of the bine relatively more than the weight of rootstock, whilst the omission of potash has the opposite effect.

Root Weight as percentage of Total Weight.

Treatment.	No. of Plants.	$\frac{\text{Weight of Rootstock} \times 100}{\text{Total Weight.}}$	S.E.
A Complete	6	89·67	·275
B No nitrogen	6	96·03	·649
C No potassium	5	83·90	1·243
D No phosphorus	6	96·78	·263
E No calcium	6	90·63	·430
F No magnesium	6	89·63	·813
G Rain water only	6	96·40	·625

In comparison with the complete nutrient series, no nitrogen, no phosphate, no potash, and rain water only show a significant difference. No calcium and no magnesium do not differ significantly from the complete series.

GENERAL DISCUSSION.

From the quantitative data presented and the general observations made on the various plant characters, it will be apparent that the deficiency treatments produced certain well marked effects on the plants.

It is of interest to discuss these and to attempt to relate them to effects which have been noted in cases where the deficiencies considered have been examined on other types of plants.

The largest effects on both vegetative growth and fruiting characters resulted from the treatments nitrogen omitted and phosphorus omitted respectively, severe stunting and failure to develop shoots and cones occurring.

These results are in accordance with those of Wallace (18) and Davis (5) for fruit trees. Eckerson (8) has pointed out the similarity between tomato plants suffering from deficiencies of nitrogen and phosphorus and has shown that phosphorus deficient plants are essentially " nitrogen starved plants," due to the relative deficiency of " reducase " which follows on deficiency of phosphorus.

The sparsity of shoots from these treatments in the present experiments corresponds with the lack of tillering in cereals which follows from deficiencies of the elements (2, 11).

The nitrogen and phosphorus deficient plants differed in respect of the times of the onset of the symptoms, being much earlier in the former case, which is in accordance with the observations of Wallace (16) for fruit trees which also contain fair reserves of phosphorus before commencing deficiency treatments. Moreover, nitrogen deficiency resulted in pale foliage, whereas those from phosphorus deficiency were downcurved and of a dull dark green colour. These foliage effects for phosphorus deficiency are characteristic for many plants (18) and are especially similar to those developed by the tomato (8).

The results from potassium deficiency were in agreement with many observations made on " potash hunger " for various plants.

Thus chlorosis (18), bronzing (6) and severe scorching (18) have all been associated previously with deficiency of the element. The good growth of bine is not unexpected since it is known that plants are able to utilize reserves of potassium for growth purposes very effectively (11). The bines in the experiment remained greener and more sappy in this series after those in the other series although observations in the field showed that potassium deficiency resulted in earlier leaf fall and defoliation. These observations are in accord with those of Wallace (18) from fruit trees under pot and field conditions, whilst Gregory and Richards (11) have shown that under certain conditions potassium deficient plants are " high moisture " plants and Mann (13) that moisture content in cases of potassium deficiency may be greatly affected by environmental conditions. The relationship shown between nitrogen and potassium has been observed for many plants and has been proved to be of very great importance in the case of fruit trees (10, 18).

The results obtained for growth in the calcium deficient series were similar to those obtained by Wallace (18) and Davis (5) for fruit trees, and the symptoms observed on the leaves were comparable to those which have been obtained on apples (18). The increased growth may be explained by the observations of Mann (13) on the decreased rate of transpiration which may occur where calcium is deficient. The characters shown by the plants differed from those which have been observed on the tomato (14), tobacco (9) and field pea (7) in which cases stunting occurs and tip foliage is affected before the older leaves. It thus appears that calcium deficiency effects may show considerable variation according to the plants considered.

The main effects of magnesium deficiency were evidenced in the foliage characters, though cone formation was affected to some extent.

The leaf symptoms were fairly comparable to those which have been obtained with other plants, the oldest leaves being affected first (9, 12). Magnesium deficiency has been the cause of serious failures of tobacco in the United States of America, and has also been shown to occur on corn, though to date no cases have been reported for crop plants in this country.

ACKNOWLEDGMENTS.

The writer desires to express his thanks to Dr. T. Wallace of Long Ashton Research Station, not only for his help and advice in the carrying out of the experiments but in making it possible for the author to present the discussion of the results in the light of other work ; and also to Mr. A. H. Burgess of the South-Eastern Agricultural College for his advice and interest. Mr. T. N. Hoblyn examined statistically the figures in Table IV, whilst Mr. M. C. Vyvyan kindly prepared the table giving the root-shoot ratios of the treatments.

SUMMARY.

1. The results of five years' observations on a pot culture experiment with hops are dealt with in this paper. Descriptions of the very definite foliage characters associated with the omission of certain elements from the nutrient solution are given, and the effects of the treatments on growth, weight of bine and rootstock, and cone formation are also discussed.

2. The omission of nitrogen and phosphorus respectively produced the most marked effects on growth and cropping, the plants being stunted, throwing very few shoots and tending to become entirely unable to develop cones. The leaves in the two cases differed markedly, being pale green in the case of nitrogen deficiency, whilst those of the no phosphorus series were a dull green colour.

3. Potassium deficiency did not affect growth to a marked extent, but tended to increase it and to lengthen the growing period. The leaves showed characteristic features, marginal leaf scorch, slight chlorosis and purpling. The symptoms were greatly accentuated by increasing the supply of nitrogen, thus widening the nitrogen–potassium ratio.

4. The effect of omitting calcium under pot culture conditions was not very marked ; the plants made good growth, but suffered from marginal scorching on the lower leaves.

5. The absence of magnesium from the nutrient solution did not affect growth significantly but gave rise to typical angular spotting and scorching of the leaves, especially on the older leaves, with a premature leaf fall and failure of the cones to develop in the last season.

6. The series receiving rain water only was indistinguishable from that receiving the no-nitrogen solution.

7. The results are discussed in which comparisons are made with deficiency effects which have been noted by previous workers on various plants.

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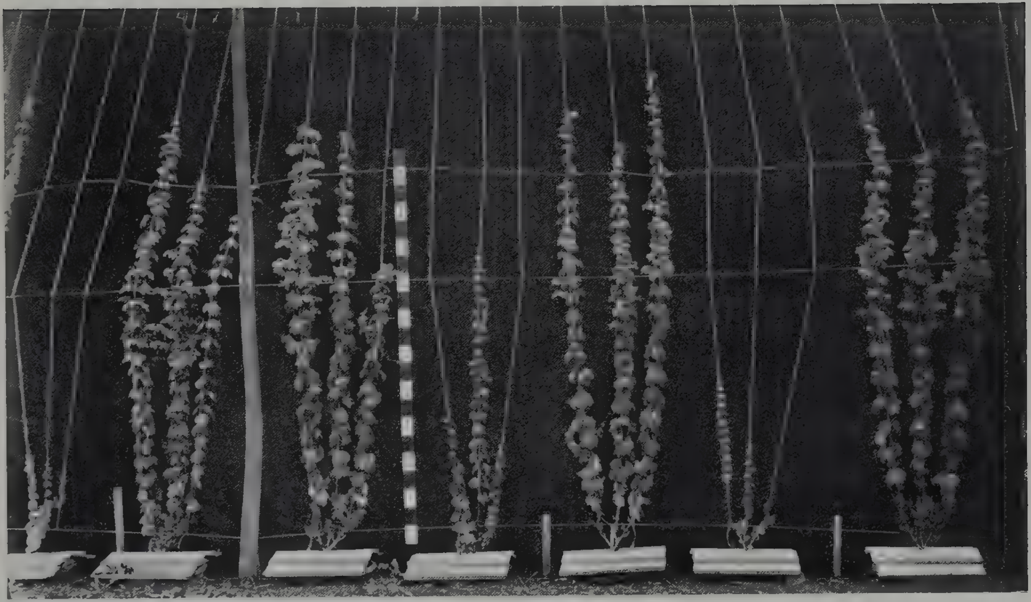
PLATE I.

Manurial Experiments with Hops.

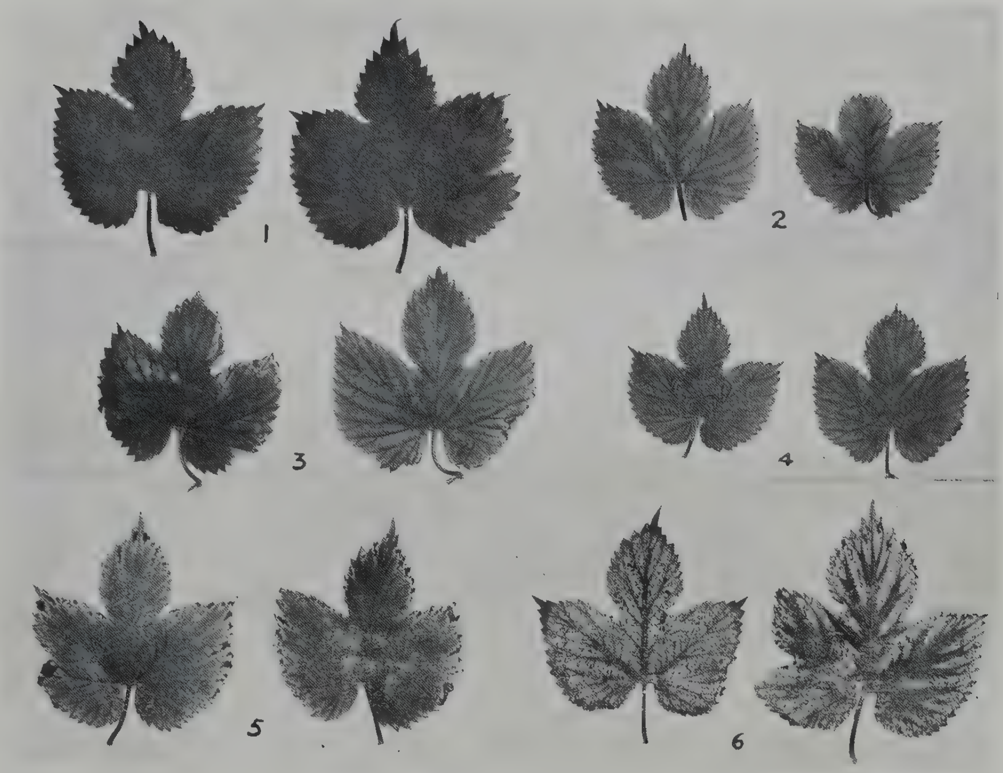


Bine growth, 1931.

1 Complete solution.
2 Nitrogen omitted.
3 Potassium omitted.
4 Phosphorus omitted.
5 Calcium omitted.
6 Magnesium omitted.
7 Rain water only.

PLATE II.

Manurial Experiments with Hops.

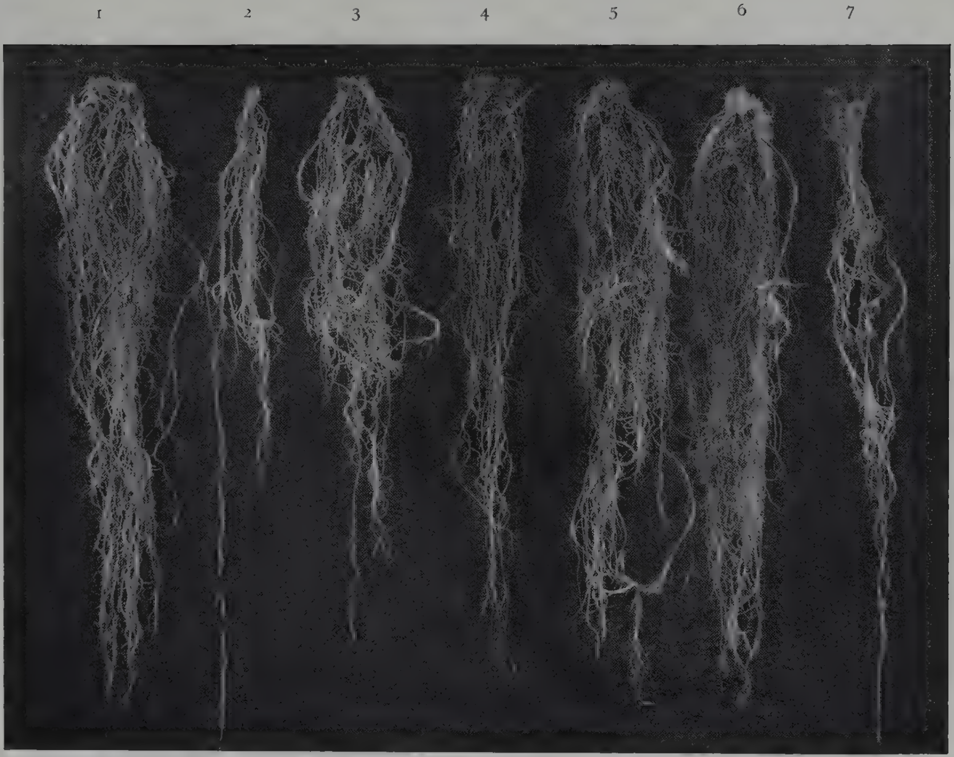


Foliage characters, 1930.

1 Complete solution.
2 Nitrogen omitted.
3 Potassium omitted.
4 Phosphorus omitted.
5 Calcium omitted.
6 Magnesium omitted.

Plate III.

Manurial Experiments with Hops.



Root systems, 1931.

1 Complete solution.
2 Nitrogen omitted.
3 Potassium omitted.
4 Phosphorus omitted.
5 Calcium omitted.
6 Magnesium omitted.
7 Rain water only.

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(*Received* 5/5/32.)

SOME INJURIOUS AND BENEFICIAL MITES ON TOP AND SOFT FRUITS.

By A. M. MASSEE,
East Malling Research Station.

Numerous species of mites occur on fruit trees in this country, and many of them are injurious to some of the more important fruits, as the apple, pear, plum, black currant and other soft fruits.

The minute acari which occur on our fruit trees have not been studied in sufficient detail in this country up to the present, and a good deal regarding their life-cycles and methods of control remains to be discovered. Therefore, it seems worth while bringing together in one article what little there is known about these acari in order to stimulate more interest in this group of animals.

For convenience it has been decided to arrange the various species under their respective host plants. Special reference has been given to the species of economic importance and, where possible, control measures are suggested or recommended. Reference is also made to some species which occur abroad, and may be found in this country at some later date. A few species which occur on "wild" fruit trees in England are also briefly mentioned.

A number of beneficial mites which are sometimes found on fruit trees and are present in sufficient numbers to be "spotted" by fruit growers are mentioned under their respective host plants.

APPLE.

The Fruit Tree Red Spider (*Oligonychus ulmi* C. L. Koch).
The Red Spider Mite (*Tetranychus telarius* L.).
The Pear Leaf Blister Mite (*Eriophyes piri* (Pgst.) Nal.).
The Apple Bud and Leaf Mite (*Phyllocoptes schlechtendali* Nal.).
The Apple Leaf Mite (*Eriophyes malifoliæ* Parrott).
Crab Apple Mite (*Eriophyes goniothorax var. malina* Nal.).
Crab Apple Leaf Pocket Mite (*Eriophyes piri var. mali* Nal.).
Crab Apple Leaf Rolling Mite (*Eriophyes piri marginemtorquens var. mali* Nal.).
The Beetle Mite (*Euzetes lapidarius* Mic.).
The Flat Scarlet Mite (*Tenuipalpus glaber* Donn.).
The Red Velvet Mite (*Allotrombidium fuliginosum* Herm.).

THE FRUIT TREE RED SPIDER (*Oligonychus ulmi* C. L. Koch) is known in the United States by the name of the European Red Mite (*Paratetranychus pilosus* Can. and Fanz.). It was first observed in that country in 1911 (1), and is said to have been imported from Europe on nursery stock.

The Fruit Tree Red Spider is widely distributed in the British Isles, and it is a pest of economic importance in most fruit centres.

The history of this mite is of interest. It was recorded on apples in this country as long ago as 1909 by Professor F. V. Theobald (2), but it was not regarded as being of any economic importance until about 1924. It was first recorded in Europe, and described by Canestrini and Fanzago (3) in the year 1878.

The reason why this pest has increased so rapidly in the last few years may be accounted for as follows. From 1922 onwards the routine methods adopted for controlling insect pests on top and soft fruits altered considerably from those measures used in the years previous to 1922. For instance, there has been a general tendency to destroy the various insects in their egg stage during the dormant season, rather than waiting until the insects hatch and then attempting to destroy them by means of contact washes and stomach poisons. For this purpose tar-oil washes have been used during the winter months. Now, while it is generally agreed that the eggs of various species of Aphides and those of the Apple Sucker are destroyed by the tar-oils, it is equally well known that the eggs of the Fruit Tree Red Spider are not killed by these sprays (4). Further, it has been shown that certain beneficial insects such as the Anthocorid Bug (*Anthocoris nemorum* L.) and species of Capsid Bugs which hibernate on the fruit trees, and elsewhere, during the winter are also killed by the applications of tar-oil washes. These insects are known to feed very readily upon the various stages of the Fruit Tree Red Spider. The fact that these beneficial insects are destroyed, and that the eggs of the Fruit Tree Red Spider are not affected, accounts very largely for the increase of this mite. It is able to breed in the spring without the natural checks it received before the advent of the tar-oil washes (5).

The adult Fruit Tree Red Spider is of a velvety red colour when first emerged, but soon turns to a dark brownish red. The bases of the spines are whitish and show up distinctly against the darker body and the red colour of the spines. The eyes are red. The male is smaller and more slender than the female.

The stages are as follows : The female deposits eggs from which are hatched the nymphs or six-legged larvæ. These moult into eight-legged proto-nymphs, which in turn change into deutonymphs, and after a final moult the adults appear.

The nymphs hatch from the winter eggs during the latter part of April and in May and commence to feed on the foliage, usually on the under surface. Summer eggs are laid on the leaves about three weeks to a month after the nymphs hatch out. The period between the hatching of the winter eggs and the oviposition of summer eggs on the leaves varies considerably according to weather conditions. The number of generations in one season also varies, but it is considered that there are at least four in an average year. There may be more generations in hot summers, or in years when the autumn is fine and warm. Another point of interest is that the generations overlap considerably, the result being that eggs, immature and adult mites, may all be present on the foliage at the same time. The winter eggs are deposited on the sheltered portions of the spurs, branches and trunks of the trees during September, October and November. The winter egg is round and somewhat flattened, and it is distinctly grooved. A long hair-like stalk arises from the centre of the egg. This stalk is frequently curved and is a little longer than the diameter of the egg. When first deposited, the egg is bright red, but later it turns a little duller. When ready to hatch, the egg becomes transparent and the shell is almost colourless. The eggs may be seen quite readily on the trees, especially in sunny, bright intervals during the winter months.

The injury caused to apple trees by the Fruit Tree Red Spider is very pronounced, and some varieties are markedly more susceptible to attack than others. Some of the more susceptible varieties are as follows: Stirling Castle, Lord Derby, Lane's Prince Albert, Laxton's Superb, Orleans Reinette, and Belle de Boskoop. Many other sorts are equally susceptible in some years.

While the fruit is not actually attacked by the mites, it is evident that it does not develop to its normal size where bad infestations occur. The mites cause most damage during the latter part of June and in July, at the period when the trees should be producing sturdy new growth. This is particularly noticeable on young trees. The foliage often turns a silvery hue, becomes very brittle, and drops off prematurely in the autumn. Severe attacks of apple mildew are frequently found in association with mite infestations, and it would appear that the two troubles combined greatly reduce the vigour of the trees.

Control Measures.

Several recommendations have been suggested for the control of the Fruit Tree Red Spider on apples, but only those which have proved to be successful will be referred to here.

There is little doubt that the best and cheapest spray to use against this pest is lime-sulphur. Lime-sulphur is also to be recommended because it is of the greatest value in controlling apple scab (6), one of the most serious diseases which the fruit grower has to contend with in England. Unfortunately, the lime-sulphur preparation will not affect the eggs of this mite. Therefore it is essential to apply the sprays, as far as possible, at the period in the spring when eggs are not present, namely after the winter eggs have hatched but before the first generation of mites commence to deposit their summer eggs on the foliage. For this purpose the sprays should be applied approximately as follows: the first spray should be applied in the pink bud stage (that is, when the flower trusses are showing pink, but before the flowers open). Formula : lime-sulphur 1 part, water 30 parts, commercial powdered spray gelatine 5 oz.

The second application should be applied immediately after petal fall at the following strength : lime-sulphur 1 part, water 99 parts, commercial powdered spray gelatine 1 lb. When the attack is very severe, a third application applied at the same strength as the second, should be made a week or ten days after the first post-blossom spray.

Under normal conditions the above programme will give sufficient control of the Fruit Tree Red Spider to render it negligible in an apple plantation.

Under certain conditions, however, the lime-sulphur programme cannot be carried out. Some varieties of apples, more especially Stirling Castle, Lane's Prince Albert, Belle de Boskoop and Beauty of Bath, are sulphur shy, and for these varieties an alternative control measure must be used. On sulphur shy varieties such sprays as pyrethrum, white oil emulsion or flour paste preparations can be applied with advantage. Of these three sprays the choice lies between the white oil and the flour paste, which are both very much cheaper than the pyrethrum extracts at present available.

A summer grade of white oil emulsion should be applied immediately after petal fall at the rate of 2 gallons of white oil to 98 gallons of water. One application is usually sufficient, but on such varieties as Lane's Prince Albert the mite infestation is often very severe, and under such circumstances a second application may prove necessary. This should be applied some seven to ten days after the first application.

In mixed plantations, especially where sulphur shy varieties of gooseberries, i.e. Leveller, are interplanted under apple trees, it is not possible to use a sulphur spray, and under these conditions flour paste can be applied with impunity. The formula is as follows : flour paste (U.S.A. formula)—" One pound of flour is made into a " batter " with a little water, and is then mixed with one gallon of water. The mixture is heated until a clear paste is formed. For spraying, 8 gallons of flour paste are used in 100 gallons of water " (7). The first spray should be applied immediately after petal fall, this being followed by a similar spray some seven to ten days later.

THE RED SPIDER MITE (*Tetranychus telarius* L.) frequently occurs on apples in this country but, compared with the Fruit Tree Red Spider, it is of little economic importance. The brick-red winter form may be found in cracks and under loose bark on old trees. All stages of the mites are to be found on the foliage during the summer months, and are readily recognized as being distinct from the Fruit Tree Red Spider by the presence of a fine web under which the mites live. The summer forms are greenish white, with darker spots.

Control Measures.

The routine applications of lime-sulphur or post-blossom white oil emulsion sprays are sufficient to keep this mite in check. A more detailed account of this mite will be found under the heading of Strawberry Mites, p. 127.

THE PEAR LEAF BLISTER MITE (*Eriophyes piri* (Pgst.) Nal.) does not often attack apples in this country, and at present it cannot be regarded as a pest of economic importance. It has been recorded on one or two occasions, however, and, since it is frequently attacking apples in the United States (8) and other countries it is worthy of brief mention.

The mites live under the bud scales during the winter months and commence to feed on the developing leaves as soon as they unfold. As the leaves develop, small pimples appear on the upper surfaces, while small blisters are present on the under surface. These blisters are of the same colour as the rest of the under surface, and are somewhat difficult to detect. The developing fruitlets and their stems are also attacked. Small blister-like patches are produced on the skin, usually around the calyx, and the stems are thickened and of a warty appearance. The infestations have not been severe enough in this country to render the fruit unsaleable.

Control Measures.

This pest is very readily controlled by spraying with a lime-sulphur preparation applied at the strength of 5 per cent. The spray should be applied as soon as the buds begin to burst and when the first appearance of green foliage is noted. One application is sufficient. This mite is referred to in greater detail under Pears, see p. 113.

THE APPLE BUD AND LEAF MITE (*Phyllocoptes schlechtendali* Nal.) has been recorded in newly planted apple orchards at East Malling and also on the foliage of wild crab apples growing at Sevenoaks and in the New Forest district. It is also found in Central Europe, Germany, and in the United States of America. In 1926 and 1927 this mite was found in numbers upon the variety of apple Hormead Pearmain. In cases of severe attack the mite causes considerable damage to the foliage, the leaves frequently drying up prematurely. The fruit is also marked with minute blisters. The mite punctures the epidermis and thus causes slightly pitted and speckled fruits (9).

When present in small numbers only, the puncturing and feeding of the acari causes the leaves to become faded and of a silvery appearance. The mites hibernate under the bud scales and beneath loose bark. They do not hibernate in large groups, rarely more than five or six mites being found under one bud-scale. The mites, which are reddish brown in colour, are not visible to the naked eye. They commence to feed on the developing foliage as soon as the buds burst.

The minute, white, pearly eggs are found on the undersides of the leaves during the summer months, but are very difficult to detect because they are deposited amongst the very fine hairs on the leaves.

A small dipterous larva (*Arthrocnodax wissmani* Kieffer) has been found feeding on this mite in England and in Germany (10).

Control Measures.

The trees should be sprayed with lime-sulphur at the strength of 5 per cent as soon as the buds burst. If two pre-blossom lime-sulphur sprays are applied to the trees as a routine for scab control, then the earlier spray at 5 per cent need not be applied.

THE APPLE LEAF MITE (*Eriophyes malifoliæ* Parrott) has been recorded in the United States of America, but up to the present it has not been found in this country. It is a free living species which is found in association with *Eriophyes piri* (Pgst.) Nal. and *Phyllocoptes schlechtendali* Nal. It occurs upon the under surface of the leaves, and it is said to be quite a common species in the apple orchards in the vicinity of Geneva and Canandaigna (8).

THE CRAB APPLE MITES (*Eriophyes goniothorax var. malina* Nal.); the Crab Apple Leaf Pocket Mite (*Eriophyes piri var. mali* Nal.) and the Crab Apple Leaf Rolling Mite (*Eriophyes piri marginemtorquens var. mali* Nal.) have been recorded by Nalepa (11) as occurring on the wild crab apple in Central Europe. None of these species have been recorded in Great Britain, and they do not occur on cultivated varieties of apples.

THE BEETLE MITE (*Euzetes lapidarius* Mic.) is commonly found on apple trees, especially in old orchards and in plantations where the trees have been neglected. This mite lives on moss and lichen and has no injurious effect upon the trees or fruit.

The Beetle Mite is minute, but plainly visible to the naked eye. Its colour varies from brick red to dark red, while some specimens are shiny black. It is commonly called Beetle Mite because of the beetle-like hardness of its body (12). The mites hibernate in large clusters on the trunks, and are sometimes so abundant that the trees have the appearance of having been coated with a dark reddish paint. Sometimes they are active during mid-winter, but they soon seek shelter in the cracks of the bark when the temperature falls, and they remain in hiding until the next warm spell of weather. The mites are not noticed so much in the summer because they disperse to all parts of the trees. Unfortunately this beneficial mite is becoming less common in the plantations since the introduction of tar-distillate washes, which destroy the wintering forms of the mite.

The Flat Scarlet Mite (*Tenuipalpus glaber* Donn.) is another beneficial species of mite which is sometimes found on apple trees.

This mite, as indicated by its name, is bright scarlet in colour, and the dorsal surface of the body is ornamented by a series of irregular grooves. The species is very much flattened and the legs are shorter, but more robust than those of the Fruit Tree Red Spider. In addition, it is much more sluggish in its habits. The Flat Scarlet Mite is a gregarious species, and the fact that it spends the winter in the adult stage, hibernating at the base of spurs and buds and in other sheltered places, at once distinguishes it from the Fruit Tree Red Spider, which spends the winter in the egg state. Observation has shown that the Flat Scarlet Mite is a beneficial species since it feeds upon moss, lichen and other foreign growths on the tree. The mite is also frequently found amongst the fine hairs on the undersides of the leaves, but there is no evidence to suggest that it feeds on the foliage.

This species has been recorded from Cambridge, Reading, Wateringbury, East Malling and Maidstone. The mites were so numerous on some apple trees in an orchard at Maidstone during the winter of 1928 that the spurs and branches of some of the trees were bright red (12).

The Red Velvet Mite (*Allotrombidium fuliginosum* Harm.) is found on most kinds of top and soft fruits, including the apple. It is the largest species of mite which occurs on fruit trees in this country. It is bright red and of a distinct velvety appearance. It occurs on the trees for the greater part of the year, but it is most frequently seen in the spring at the period directly preceding the flowering of the apples. At this time the mites are found walking up and down the stems in a very stately manner (12).

It passes the winter in the adult stage, resting amongst dried leaves, in dry soil, and under loose bark on the trunks of the trees. Eggs are laid in the spring. This mite is predaceous, and has been observed feeding upon colonies of woolly aphides during the summer months.

PEAR.

The Pear Leaf Blister Mite (*Eriophyes piri* (Pgst.) Nal.).
The Pear Leaf Rolling Mite (*Eriophyes piri marginemtorquens* Nal.).
The Free Living Pear Mite (*Epitrimerus piri* Nal.).
The Apple Bud and Leaf Mite (*Phyllocoptes schlechtendali* Nal.).
The Fruit Tree Red Spider (*Oligonychus ulmi* C. L. Koch).
The Red Spider Mite (*Tetranychus telarius* L.).
The Bryobia Mite of Pear (*Bryobia cristatus duges.*).
The Gooseberry Bryobia (*Bryobia nobilis* Th.).

THE PEAR LEAF BLISTER MITE (*Eriophyes piri* (Pgst.) Nal.) is undoubtedly the most important species of mite which is found on cultivated pears in this country. Fortunately, however, it is rarely a pest of great economic importance in large pear plantations. It occurs most frequently on cordon pears growing on walls, on pot pears under glass, and sometimes on pears growing in the open, in the sheltered parts of plantations and then mainly on bush pears. Sometimes the Pear Leaf Blister Mite is very troublesome in the nursery beds, since it gives the maiden and two year old trees a very unsightly appearance, and also tends to check the terminal growths.

The damage caused by this pest is too well known to need a lengthy description. The mites hibernate under the bud scales during the winter months. They commence to feed as soon as growth begins in the spring, and many mites may be found in the curled leaves before they have time to expand fully. The mites make conspicuous blisters on the upper surfaces of the leaves, which frequently cover the whole surface. Sometimes hundreds of blisters are present on a single leaf in May and June but, even so, the mites are very difficult to find because they live and breed inside the tissue. The mites also feed on the petals and the developing fruitlets. The immature fruits are marked and distorted, many of the attacked fruits falling off prematurely. Some varieties of pears are more subject to attack than others, the variety Emile d'Heyst being very susceptible to attack.

The Pear Leaf Blister Mite is very widely distributed. It has been recorded from most parts of Europe, all over the British Isles, from America, and from Canada.

Control Measures.

Fortunately, the Pear Leaf Blister Mite is one of the easiest pests of the pear to eradicate. It may be controlled efficiently in the plantation, on pears growing on walls, and in the nursery beds by spraying with lime-sulphur applied at the rate of 5 per cent. The spray should be applied as soon as the buds commence to open, which in this country usually obtains round about the second or third week of March. One application at this strength is usually sufficient. Pears under glass should receive the same treatment, but the spray must be applied a little earlier, the time depending upon the temperature of the house concerned.

In the nursery bed, the spray can be applied efficiently by means of a knapsack sprayer, care being taken to wet each bud with the acaricide.

THE PEAR LEAF ROLLING MITE (*Eriophyes piri marginemtorquens* Nal.) and the FREE LIVING PEAR MITE (*Epitrimerus piri* Nal.) are recorded from the wild and cultivated pear respectively, but both species are rare and they cannot be regarded as pests. Both species are found in Europe (11) and the latter also in America (8). They have not been recorded in this country.

THE APPLE BUD AND LEAF MITE (*Phyllocoptes schlechtendali* Nal.) also feeds on the pear, but in this country it is very rarely found on cultivated pears, and it is of no importance to the fruit grower. In America it is recorded on pears, but it is not regarded as an important pest. It is also found on the continent of Europe. Further details of the habits of this mite are given under the heading of Apples, p. 110.

THE FRUIT TREE RED SPIDER (*Oligonychus ulmi* C. L. Koch) is frequently found on pear leaves during the summer months, but it does not appear to cause any material harm to the trees as compared with the damage caused to apples and plums. The winter eggs are sometimes present on the spurs and trunks of pear trees, but the number is usually very small. Whether this pest will become important on pears remains to be seen. In the pear growing areas around Faversham it is certainly much more prevalent now than it was a few years ago. Further details appear under the headings of Apples and Plums.

THE RED SPIDER MITE (*Tetranychus telarius* L.) very rarely attacks pears in the plantation, but it may be a source of trouble where pears are growing on walls or under glass. It also occurs on pears in the nursery beds, especially during spells of warm weather, during the summer months. The treatment recommended for the control of the Pear Leaf Blister Mite will serve to keep this pest in check. When spraying espalier or cordon pears on walls, it is essential to drive the spray into the crevices of the walls because these are favourite places for hibernation purposes.

THE BRYOBIA MITE OF PEAR (*Bryobia cristatus* Duges.) was recorded on pears in the Faversham district some two years ago, but the damage caused by this mite was not regarded as being serious. The species is very similar to the Gooseberry Bryobia, and it is capable of running about on the foliage very rapidly. It is dark red in colour, the body is oval shaped and somewhat flattened, and the legs are long and conspicuous. It is a little larger in size than the adult Fruit Tree Red Spider. It hibernates in the adult stage upon the pear.

THE GOOSEBERRY BRYOBIA (*Bryobia nobilis* Th.) has been found on pears in this country, but it is not considered to be of any importance. It is usually present in plantations where pears are growing with gooseberries as an undercrop, and it is considered that the mites migrated from the gooseberries to the pears. It is well known that the Gooseberry Bryobia migrates from one host plant to another very readily. A fuller account of this mite appears under the heading of Gooseberry, p. 122.

PLUM AND DAMSON.

The Fruit Tree Red Spider (*Oligonychus ulmi* C. L. Koch).
Eriophyes phloecoptes Nal.
Eriophyes similis Nal.
Phyllocoptes fockeui Nal.
Eriophyes padi prunianus Nal.
Epitrimerus gigantorhynchus Nal.
The Beetle Mite (*Euzetes lapidarius* Mis.).
The Red Spider Mite (*Tetranychus telarius* L.).

THE FRUIT TREE RED SPIDER (*Oligonychus ulmi* C. L. Koch) has been referred to in some detail at the beginning of this paper, but since it is probably just as important on plums and damsons, further details must be given here.

As already mentioned, the advent of tar-oil washes is regarded as being the primary cause of the increase of the Fruit Tree Red Spider on apples. If that is so, then the same thing applies, but to a greater degree, to plums and damsons. Plums and damsons have been sprayed as a matter of routine with tar-oil washes year after year, because such important pests of these stone fruits as the Leaf Curling Plum Aphis, the Mealy Plum Aphis and the Hop-Damson Aphis are completely wiped out if the winter wash is applied efficiently. Now, unlike apples, plums and damsons are not affected by the scab fungus, and in consequence routine applications of lime-sulphur sprays have not followed the winter wash. The result is that plums and damsons all over the country are now suffering yearly from increasing infestations of the Fruit Tree Red Spider. The importance of this pest on plums and damsons was discussed by the writer in an article published in 1930 (12).

Methods of Control.

The control measures suggested for eliminating the Fruit Tree Red Spider on apples cannot be applied to the plum and damson also. This is unfortunate, but may be accounted for by the fact that plums and damsons flower earlier than the apple. Since the sprays used for controlling this pest are directed against the adult and immature stages of the mites, and *not* the eggs, it is useless spraying before the blossom period in the case of plums and damsons because none of the winter eggs have hatched at this time. It has been shown in experiments (13) that a majority of the immature forms have hatched from the overwintering eggs some few days after petal fall, and it has been ascertained that in the case of the Victoria plum the best time to spray is about ten days after the flowering period. At this period the least number of eggs (the overwintering forms or the first summer brood) are present on the trees. If the post-blossom spray can be applied at the critical time, then one spraying proves to be efficient. The lime-sulphur-gelatine spray should be applied ten days after petal fall, at the strength of 1 per cent. This spray can be applied to all commercial varieties of plums and damsons without ill effect upon the trees or upon the crop.

The vexed question of mixed plantations must be considered. Where apples and plums are growing in the same orchard, it is often impossible to spray both the apples and plums at the same time. When the plums are ready for their first treatment, the apples are in flower, and if one waits until the apples are ready for the post-blossom spray, then the mites on the plums have got out of control. The apples and plums in such plantations should be treated separately.

When plums and sulphur shy varieties of apples are interplanted, a 2 per cent white oil emulsion must be used instead of lime-sulphur.

One very interesting point regarding the Fruit Tree Red Spider on both apples and plums is as follows. The egg population on the trees during the winter months does not necessarily give a true idea of the degree of the infestation which may result the following spring. Although the trees may be red with eggs during the winter, the infestation the following season may be slight. Conversely, a few eggs may result in a severe infestation in the following summer. The severity of an attack seems to depend upon, first, the number of viable eggs present and, secondly, suitable weather conditions for allowing the mites to breed rapidly. Ideal weather conditions are difficult to define. It is no longer considered that hot, dry weather is essential for the rapid development of the mite. Provided the conditions are more or less constant, then the mite will breed whether the temperature is comparatively high or low.*

Eriophyes Phloecoptes Nal., *Eriophyes similis* Nal. and *Eriophyes padi prunianus* Nal. occur on plums in this country, but it is very doubtful whether they cause any serious harm to the trees or the crop. It is very probable, however, that their presence on the trees during the winter months accounts for some species of birds, for example tits, " working " the buds and destroying them. Plum trees " worked " by birds have been examined and these minute acari have been present in some numbers. The mites shelter under the bud scales. The galls made by *E. phloecoptes* Nal. are very characteristic. Little groups of galls one-twelfth of an inch in diameter are formed at the base of the spur. Twenty or thirty galls are sometimes present on one spur, which is somewhat swollen and of a warty appearance. This species is rare in this country.

** Although it has been proved that applications of lime-sulphur are not toxic to the eggs of the mite, there is reason to suppose that the presence of sulphur tends to check the mite in the plantation. Thus, plantations receiving two pre-blossom lime-sulphur sprays, applied at five and three per cent respectively, are rarely badly infested with this pest. It is considered that the " sulphur-atmosphere " in the plantation destroys many of the nymphs of the first brood when they hatch from the winter eggs.*

E. similis Nal. and *E. padi prunianus* Nal. both produce conspicuous pouch-shaped galls on the foliage (11). They are widely distributed in this country, but they cannot be considered common species.

Phyllocoptes fockeui Nal. and *Epitrimerus gigantorhynchus* Nal. are free living species which are found on the under surfaces of the leaves during the summer months, and under the bud scales during the winter time. *P. fockeui* Nal. sometimes causes the foliage to turn silvery, giving the trees the appearance of having been attacked by Silver Leaf. *P. fockeui* Nal. is a very common species, and is frequently so numerous under the bud scales of plums and damsons in the autumn and winter months, that the trees are stripped of their buds by birds.

THE BEETLE MITE (*Euzetes lapidarius* Mic.) is commonly found on plums and damsons in this country, more especially in old, neglected plantations. It feeds on the lichen and moss, and when the plums and damsons are ripe the mites often feed on the fruits which have already been attacked by wasps or have been split open by the wet weather conditions.

THE RED SPIDER MITE (*Tetranychus telarius* L.) frequently lives upon plum and damson foliage, and it is probably more common on these stone fruits than upon the apple and the pear. It is often present on newly budded stocks in the nursery beds, and tends to check the growth of the plants. The attacks are rarely severe enough to warrant control measures being needed, and at most a sulphur spray should suffice.

CHERRY.

The Beetle Mite (*Euzetes lapidarius* Mic.).
Phyllocoptes fockeui Nal.

THE BEETLE MITE (*Euzetes lapidarius* Mic.) is very common in cherry orchards in Kent, and is definitely harmful under certain conditions. It is one of the curious anomalies of a beneficial mite becoming a pest for a short period during the year.

In normal circumstances, the Beetle Mite feeds on foreign growths on the trees. However, during June and July, especially in wet seasons, the mites migrate from the leaves and shoots and feed on the fruits. They feed on juices of the fruits which have split open during a period of rainy weather, and are frequently so numerous that the fruits have to be washed before sending them to market. This mite will not attack sound fruits (9). Now that tar-oil washes are being used in cherry orchards, this mite is less common, and if it should be found to be troublesome in a cherry orchard, an application of tar-oil at 5 per cent will eradicate the mite. The spray should be applied in December.

Phyllocoptes fockeui Nal. This free living species of gall mite is recorded from Central Europe (14), Italy and Sicily. It lives under the bud scales during the winter months, and feeds on the foliage during the summer. When the attacks are severe, the foliage turns brown in colour. It has not been recorded in England, and is of no economic importance.

PEACH, NECTARINE AND APRICOT.

The Silver Leaf Mite (*Phyllocoptes cornutus* Bks.).
The Red Spider Mite (*Tetranychus telarius* L.).

The Silver Leaf Mite (*Phyllocoptes cornutus* Banks.) occurs in the Eastern States of North America (15). It has not been recorded in Europe. It is a free living species of gall mite which feeds on the foliage of peach trees. The mite is said to produce a sort of silvery sheen on the leaf which is readily discernible when the light is shining upon it. It is not considered to be an important pest of these stone fruits.

The Red Spider Mite (*Tetranychus telarius* L.) is found on the peach, nectarine and apricot in this country, and in many other parts of the world. In England it is only troublesome on trees growing under glass, and those growing against walls, especially in sheltered positions. The damage caused by this mite may prove to be quite serious, and trees under glass are frequently defoliated by this pest. The mites feed on the foliage, causing it to develop a silvery hue which is very conspicuous. The foliage often drops off prematurely. Where this pest occurs under glass, it is imperative to keep the house clean, especially in the winter months. At this period the mites hibernate (in the brick red form) in any cracks and crevices they can find (16). They remain in hibernation until the following spring, when they migrate to the plants or trees and commence feeding upon them. It is possible to keep the mite in check by spraying with a 2 per cent lime-sulphur spray early in the year just before the flowering period. This treatment, combined with liberal applications of water to foliage each night and morning, will prevent a severe infestation. The same treatment applies to trees on walls, but in this case care must be taken to destroy the mites which are hibernating in the cracks in the walls. This object can be achieved best by spraying with a tar-distillate wash at the strength of 5 per cent, in December. This winter wash must be followed up by the 2 per cent lime-sulphur spray just prior to the flowering period, and again immediately after the flowering period, if necessary, at a strength of 1 per cent.

WALNUT.

The Walnut Blister Mite (*Eriophyes tristriatus* Nal.).
The Free Living Gall Mite (*Phyllocoptes unguiculatus* Nal.).
Eriophyes caulis Cook.
The Fruit Tree Red Spider (*Oligonychus ulmi* C. L. Koch).
The Red Spider Mite (*Tetranychus telarius* L.).

THE WALNUT BLISTER MITE (*Eriophyes tristriatus* Nal.) is a very common species which occurs in many parts of Europe, the British Isles and in North America. It produces large conspicuous blisters on the leaves. The mites live under the bud scales during the winter months. Although the mite is present on the majority of walnut trees growing in England, it does not appear to do any harm. In the South of England the mite is often abundant, and frequently most of the leaves on old trees are distorted by its attacks. An interesting study of this species has recently been made by Hassan (17).

THE FREE LIVING GALL MITE (*Phyllocoptes unguiculatus* Nal.) has been recorded by Nalepa (18) from Central Europe. It infests the under surfaces of the foliage, causing it to turn brown in colour. It is a rare species of no economic importance.

Eriophyes caulis Cook has been recorded in America on walnut by Cook (19). It produces brown Erineum galls around the leaf stalks and also distorts the main veins of the leaves. It has not been recorded in Europe, and it is not regarded as a pest of economic importance.

THE FRUIT TREE RED SPIDER (*Oligonychus ulmi* C. L. Koch) and the RED SPIDER MITE (*Tetranychus telarius* L.) both occur on the walnut in England, but neither species has been observed to cause any damage to the trees.

NUT.

The Nut Gall Mite (*Eriophyes avellanæ* Nal.).
Eriophyes vermiformis Nal.
Anthocoptes loricatus Nal.
Phyllocoptes comatus Nal.
Oxpleurites depressus Nal.

THE NUT GALL MITE (*Eriophyes avellanæ* Nal.) is one of the commonest species of gall mites which is found in this country. It abounds in the majority of the Kentish cob nut plantations and is present in most of the hedgerows where the hazel is growing. It is recorded from all over Europe, from the United States of America and Canada.

The mites infest the buds, usually the leaf buds, causing them to swell abnormally, and producing the well known " Big Buds." The enlarged buds are most conspicuous during the months from November to May. The mites also attack the catkins and the female flowers (20) but this type of injury is comparatively rare.

Although this species is common everywhere, it does not appear to cause any material damage to the nut bushes and, provided the female flowers are not infested, this mite can be disregarded entirely.

When the female flowers are infested, some measure of control can be obtained by spraying with lime-sulphur, applied at 5 per cent, at the period when the mites are migrating in the spring, namely between the last week of March and the third week of April. The period of migration varies according to weather conditions.

Eriophyes vermiformis Nal. feeds on the hazel and cultivated nuts. It is usually found in association with *E. avellanæ* Nal. in the so-called " Big Buds." It also occurs on the leaves, producing abnormal hairs on the undersurface (20). Distribution : East Malling and Maidstone, Kent ; Central Europe, Finland.

Phyllocoptes comatus Nal. is a free living species which is found on the leaves of hazel, which turn brown after being attacked. Distribution : Central Europe (20).

Oxypleurites depressus Nal. is a very rare species of gall mite which lives in association with *P. comatus* Nal. and is found amongst the fine hairs on the undersurface of the leaves. In appearance the mite is very distinct from all other species found on *Corylus avellana* L. Distribution : East Malling, Kent ; and Central Europe (20).

QUINCE.

Eriophyes piri var. orientalis (Fockeu.) Nal.

This mite produces typical pustule-shaped galls on the leaves, the entrance to the galls being situated on the upper surface of the foliage. The species occurs in Europe, but it has not been recorded in England or from America (11).

RED, WHITE AND BLACK CURRANTS.

The Black Currant Gall Mite (*Eriophyes ribis* (Westw.) Nal.).
Phyllocoptes masseei Nal.
Oxypleurites neglectus Mass.
Anthocoptes ribis Mass.
The Red Spider Mite (*Tetranychus telarius* L.).

THE BLACK CURRANT GALL MITE (*Eriophyes ribis* (Westw.) Nal.) is a familiar name to every black currant grower in this country, and more has been published about this mite than any other species found in England.

The mites infest the buds of all cultivated varieties, producing the well-known " Big Buds." The buds begin to swell in August and may be detected from that period until the following May. Investigations have shown that the mites migrate from the Big Buds (21) during the latter part of March and in April, and it has been found that this period is the best one for eradicating the mite from commercial plantations.

Control Measures.

A great deal has been written about the control of the Black Currant Gall Mite, but only the essential details will be noted here. The bushes should be sprayed with a preparation of lime-sulphur in the spring (some time about the last week of March or the first week of April) when the flower racemes appear, but before the flowers actually open—when the flowers are in the " grape " stage. The lime-sulphur should be applied at a strength of 1 part of lime-sulphur to 12 parts of water. A spreader need not be used, and one application is sufficient (22). This spraying should be done each year as a matter of routine, and it is essential that young bushes should be sprayed, even the material in the cutting beds. The spray will not injure the young plants.

Some varieties of black currants are susceptible to spray injury when lime-sulphur is applied at the strength of 1 in 13, and for such varieties the strength must be reduced to 1 in 20 : then the damage factor will be partially eliminated. The varieties affected are those contained in the Goliath group, Edina and Davison's Eight. Other sorts such as Baldwin and Boskoop Giant should receive the stronger concentration.

It is important to control the Black Currant Gall Mite as far as possible in the plantations because, apart from the fact that it destroys many of the buds, it is also considered to be a vector of the Reversion disease of black currants (23), a disease which spreads rapidly and materially affects the cropping of the bushes.

The Black Currant Gall Mite also infests the buds of red and white currants, but the type of injury caused by the mite to these host plants is very different from that of black currants. Instead of producing " Big Buds," the mite-infested buds on red and white currants remain small and do not develop normally. The infested buds are very difficult to detect in the field, and some little practice is essential before this pest can be diagnosed in the plantation. The best time of the year to find the mites is in the spring, during March. At this period the normal buds are beginning to develop into growth, while the mite-infested ones remain dormant. All the dormant buds on a bush are not necessarily attacked by this mite, so it is imperative to examine the buds in detail by means of a powerful hand lens or binocular microscope.

The varieties Fay's Prolific and Raby Castle are particularly susceptible to mite attack. Other varieties are infested to a lesser degree (24). The dormant buds are sometimes very common on red currants, and fruit growers have been misled by thinking the bushes have been " worked " by birds, whereas in reality the cause of the trouble has been the Black Currant Gall Mite. Unfortunately the treatment recommended for black currants does not apply equally well for red and white currants. It may be that the life-cycle of the mite varies on the different species of Ribes. It has been ascertained, however, that an application of lime-sulphur, applied at the strength of 1 in 30 just before the flowers open, tends to check the mite. Further information on the habits and control of this mite are being obtained.

Phyllocoptes masseei Nal. is a free living species of gall mite which lives on the lower surfaces of the leaves of black currants. It is an uncommon species which up to the time of writing has been recorded only at Sevenoaks and East Malling, Kent (20).

Oxypleurites neglectus Mass. also occurs on the under surfaces of the leaves of black currants. It is a free living species which is usually found in association with *P. masseei* Nal. Recorded from East Malling, Kent. Rare (20).

Anthocoptes ribis Mass. is also a free living species which lives on both surfaces of the leaves of black currants, causing the foliage to turn a reddish tint. It has been recorded from Ontario, Canada and at East Malling, Kent. It is of no economic importance (25).

GOOSEBERRY.

The Gooseberry Bryobia (*Bryobia nobilis* Thom.).
The Red Spider Mite (*Tetranychus telarius* L.).
The Black Currant Gall Mite (*Eriophyes ribis* (Westw.) Nal.).

THE GOOSEBERRY BRYOBIA (*Bryobia nobilis* Thom.) is a very interesting species of mite which attacks cultivated varieties of gooseberries and is frequently very harmful. It hibernates during the winter in the adult stage in any sheltered position available. It often shelters in the cracks in the spile fences, in crevices in old gate posts, in dwelling houses, old buildings, and amongst ivy growing in the hedgerows. The mites migrate in the spring to the gooseberries, where they may be found in thousands on the undersides of the leaves as soon as they unfold (12). During April the mites remain near the ground level in the centres of the bushes. When the weather becomes warmer during May the mites swarm all over the bushes, causing severe damage to the new growth. On entering an infested plantation one gets the impression that the bushes are starved or lack some manurial treatment, but a closer examination soon reveals the cause of the trouble. The leaves are curled, sickly yellow in colour, and a large percentage fall off in June. The fruit is also small and stunted, and is of little commercial value.

Control Measures.

Sometimes the mites hibernate on the gooseberry bushes and in this case the control is simple. An application of 5 per cent tar-distillate wash is very efficient. It should be applied in December. It is much more usual for the mites to migrate to the bushes in the spring, and in these circumstances a tar-distillate spray cannot be used. For such attacks, an application of 2 per cent lime-sulphur should be made directly after the flowering period. It must not be applied before, since many of the mites will not have returned to the plants. When applying the spray, care must be taken to wet the undersides of the leaves, especially those at the centre of the bushes, because the majority of the mites occur in such places. One application is usually efficient. On sulphur shy varieties of gooseberries, i.e. Leveller and Keen's Seedling, a 2 per cent white oil emulsion should replace the lime-sulphur spray. Apply the spray after the flowering period, and repeat at the same strength a week later.

THE RED SPIDER MITE (*Tetranychus telarius* L.) is nearly always present on cultivated gooseberries, but it rarely infests them sufficiently to cause any material damage. Bad infestations have been noticed in the autumn, but by this time the fruit has been gathered, and most of the growth has developed before this date.

The same treatment controls this mite as that recommended for the Gooseberry Bryobia.

THE BLACK CURRANT GALL MITE (*Eriophyes ribis* (Westw.) Nal.) attacks the gooseberry in addition to the red, white and black currant, the damage being similar to that described on red currants: namely, the infested buds dry out, leaving many so-called blind buds on the bushes. This pest is not very common on gooseberry at present, but since it appears to be increasing in some parts of Kent, it may prove to be important in the future.

RASPBERRY.

The Raspberry Free Living Mite (*Eriophyes gracilis* Nal.).
The Red Spider Mite (*Tetranychus telarius* L.).
The Fruit Tree Red Spider (*Oligonychus ulmi* C. L. Koch).

THE RASPBERRY FREE LIVING GALL MITE (*Eriophyes gracilis* Nal.) is a common species on cultivated raspberries, but on account of its very minute size it is seldom seen. It is widely distributed in England, Europe and America, but it has not been recorded as a pest from any of these countries. It is possible that the mite may be associated with the abnormal growth which is frequently found on raspberries in this country (26). The mites are often present on plants which grow abnormally, but there is no evidence to suggest that the mite is directly or indirectly responsible for the disease. Three other species of gall mites have been recorded on raspberry. They are *E. essigi* hassan, *E. rubicolens* Can., and *E. gibbosus* Nal. All three species are rare on this host plant and are of no economic significance.

The Red Spider Mite (*Tetranychus telarius* L.) is found abundantly on cultivated raspberries in this county. It is generally more conspicuous in the autumn, but may be seen commonly at other periods of the year. It frequently hibernates on the canes, at their base among the roots, and in the soil.

It is probable that this species is attracted to the raspberry, especially some cultivated varieties, because of the curled nature of the leaves, which affords the mites plenty of shelter, especially during unsettled weather. The growth of the canes does not appear to be affected by the mites, and there is no need to carry out control measures against this mite in the field.

The Fruit Tree Red Spider (*Oligonychus ulmi* C. L. Koch) is sometimes found on the raspberry, especially when this soft fruit is growing under apples and plums. The mites frequently deposit their eggs on the canes in the autumn, and the immature mites which hatch out in the following spring feed on the tender foliage. It has not been reported as a serious pest on raspberry in this country.

BLACKBERRY, LOGANBERRY AND HIMALAYA BERRY.

The Redberry Mite (*Eriophyes essigi* Hassan).
The Raspberry Free Living Mite (*Eriophyes gracilis* Nal.).
Eriophyes gibbosus Nal.
Eriophyes rubicolens Nal.
Eriophyes silvicola Can.
Eriophyes rubierineus Nal.

The Redberry Mite (*Eriophyes essigi* Hassan) which causes the Redberry disease of cultivated blackberries in this country and in America is undoubtedly the most important species. The mites feed upon the drupelets as soon as the petals fall, the result being that the fruits become distorted, abnormal ripening and the abnormal red condition of the fruit being other definite symptoms of mite attack. The berries ripen prematurely when the attack is very severe, and many of them remain on the plants in a dried-up condition until the following spring (27). The mites pass the winter under the bud scales in the adult stage. The mites have been recorded on wild and cultivated blackberries, loganberries and Himalaya berry in this country; in America it occurs upon Himalaya blackberry, loganberry, raspberry and blackberry.

Control Measures.

Control measures have not been attempted in this country at present, but, according to Essig (28), the early lime-sulphur treatment is cheap and effective in the United States. This consists of spraying the bines in the spring as soon as growth develops, with a 4 per cent lime-sulphur spray. One spray is sufficient if it is applied thoroughly.

The five following species of gall mites have been recorded on cultivated blackberries: *Eriophyes gracilis* Nal., *E. gibbosus* Nal., *E. rubicolens* Nal., *E. silvicola* Can., and *E. rubierineus* Nal.

They have been recorded in Europe and some of them occur in the United States, but very little is known about their habits, and their economic status has not been defined. All the species are very minute, and are seldom noted by the casual observer.

STRAWBERRY.

The Strawberry Tarsonemus (*Tarsonemus fragariæ* Zimm.).
The Pallid Mite (*Tarsonemus pallidus* Bks.).
The Red Spider Mite (*Tetranychus telarius* L.).
Phyllocoptes segiter Nal.

THE STRAWBERRY TARSONEMUS (*Tarsonemus fragariæ* Zimm.) has been recorded on cultivated strawberries in this country and most of the countries in Europe (29), including Germany, where it is described as a very serious pest. It does not occur in America, but a closely allied species is found there, and the damage caused by it is very similar to that caused in England by *T. fragariæ* Zimm. The mites feed on the upper surface of the leaflets, always attacking the small leaflets before they are unfolded. When the infested leaves eventually open, they are found to be very much crinkled, malformed and very brittle. The mites have no eyes, they object to the direct daylight, and usually move about at night. Once a leaf has unfolded, the mites do not attack it. Eggs, immature forms and adult mites are present on the plants during the spring and summer months, but after September and until March the adult females only are present (30). Runners are attacked as soon as they commence to grow, the mites migrating along the stolons from the parent plants, and establishing themselves at the growing point of the runner. This form of natural migration is very serious, since it means that runners cannot be selected from a plantation in which the parent plants are infested with mites.

Most varieties of strawberries appear to be susceptible to attack, and Royal Sovereign, The Duke, and Laxton are often severely infested.

Control Measures.

Once strawberry plants or runners become infested with mites, it is very difficult to destroy the small acari on account of their very obscure habits. It will be remembered that they live in the crowns of the plants and in the young folded leaflets.

Some measure of success has been obtained by dipping the runners in 3 per cent lime-sulphur before planting. This should be done some time between September and March when the mite population is at its lowest, and when eggs and nymphs are not present to any extent on the plants. In order to make the lime-sulphur stick to the plants a spreader should be added. For this purpose 1 lb. of commercial powdered spray gelatine should be added to each 100 gallons of wash, or a sulphonated oil, at the rate of 2 lb. should be used. When dipping the plants care should be taken not to wash all the soil off the roots, and the plants should be allowed to dry off before being planted in the field. The mite is still more difficult to control in established strawberry beds, and at present only suggestions can be made. Some control can be obtained by spraying the plants during the first week of March with a lime-sulphur spray, plus 1 lb. of commercial spray gelatine. The spraying should be repeated ten days later. The object of spraying at this period is to destroy the adult female mites when they commence to feed in the spring, but before they deposit their eggs on the foliage. The spraying must be done very carefully, care being taken to wet thoroughly the crowns of the plants. It is not necessary to wet the undersurfaces of the old foliage when spraying against this pest.

Lime-sulphur can be used on all commercial varieties, at the strength of 3 per cent without fear of damaging the plants. Later applications of lime-sulphur can be made if necessary at the strength of 1 per cent.

THE PALLID MITE (*Tarsonemus pallidus* Bks.) is very closely allied to the Strawberry Tarsonemus *T. fragariæ* Zimm. However, it is a distinct species which occurs in the United States and in Canada. In those countries it attacks the cyclamen, chrysanthemum, delphinium, snapdragon and the geranium as well as the cultivated strawberry (31). The European species has been found only on the strawberry. The damage caused to the strawberry plant by the Pallid Mite is similar to that described above under the heading Strawberry Tarsonemus. Control measures are being investigated in the States and in Canada.

THE RED SPIDER MITE (*Tetranychus telarius* L.) is frequently a very serious pest on strawberries, and it is rather extraordinary that this mite should have been neglected so long on this soft fruit. As noted already, the Red Spider Mite attacks most sorts of top and soft fruits, so it is not surprising that it is common in the strawberry plantations.

The mites hibernate during the months from October until March in the soil, in dead leaves, in the crowns and other sheltered parts of the plants, and very often in old litter which is frequently present in the plantations. At this period, the brick red forms, namely the adult females, are the only forms present. In the spring, some time during March, the females commence to feed on the leaves and deposit their eggs on the undersides of the foliage. It is a curious fact that the majority present in the spring feed on the old leaves, and not the tender new growths as might be expected. From April until September, all stages of mites and their eggs are present on the plants (32). The generations overlap during the summer. The mites damage the leaves by feeding upon them, and when the attack is severe, the green appearance of the foliage tends to disappear. The leaves become brittle and the growth is checked. Most damage occurs in June, July and August.

Control Measures.

It is very fortunate that the control measures recommended for the Strawberry Tarsonemid Mite apply equally well for this pest. This proves to be the case because the life-cycles of the two mites are very similar. One point of difference must be taken into account when spraying in an established plantation. When spraying against Strawberry Tarsonemus, it is not necessary to wet the old leaves on the plants. This is absolutely essential where the Red Spider Mite is concerned.

Phyllocoptes segiter Nal. has been recorded from Central Europe by Nalepa (33). Its host plants are *Fragaria collina* Ehoh, *F. elatior* Ehoh, and *F. vesca* L. The mite produces red cephaloneon-shaped galls on the leaves. It has not been recorded on cultivated strawberries.

SUMMARY.

1. The literature in relation to the fruit tree mites and their control is so scanty and is scattered in so many periodicals, that it is not easily accessible for reference purposes; therefore an attempt has been made to bring together known facts of descriptions, life-history and control measures.

2. In addition, many original observations and new recommendations for control are included.

3. Some species of mites which occur abroad, and may be found here at some future date, are briefly referred to.

4. A number of beneficial mites are referred to under their respective host plants.

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(*Received* 12/5/32.)

CHLOROSIS OF DECIDUOUS FRUIT TREES DUE TO A COPPER DEFICIENCY

By F. G. ANDERSSEN,
Division of Plant Industry, Department of Agriculture, Union of South Africa.

INTRODUCTION.

Of all the symptoms of malnutrition or physiological disorders of plants discussed in the literature, that of chlorosis has probably received more attention than any other.

Chlorosis caused by an excess of lime in the soil, often known as lime induced chlorosis, is no doubt the oldest type of chlorosis referred to. Most of the earlier investigators (16) assumed that the excess of $CaCO_3$ in the soil caused the iron to be precipitated before the roots could absorb it so that there was a deficiency of iron for chlorophyll formation in the plant. Other workers, however, found very little or no difference in the iron content of chlorotic and non-chlorotic leaves (1,38,28), so that it is now generally considered that the chlorotic condition in the case of lime-induced chlorosis is due, not simply to a shortage of soluble iron absorbed by the roots, but to a deficiency of iron in an easily available form inside the plant (1, 32, 5, 48).

Of the many other causes to which the symptom of chlorosis has been ascribed the most important are a deficiency of manganese (15, 14, 33, 53, 28, 7, 2, 41, 51, 52, 23), a deficiency of sulphur compounds (25, 30), a deficiency of magnesium (19, 13, 17, 53, 12), an excess of manganese (18, 21), a deficiency of potassium (39, 47, 53, 49, 45), a deficiency of nitrogen (4, 31) and an excess of boron (42).

DESCRIPTION OF THE MALADY.

Appearance of trees.

Most of the work herein described was carried out with material from trees growing in the Ceres district in the Western Cape Province of South Africa.

In most of the neighbouring districts, however, a very similar malady occurs extensively, and, to judge from observations only, the remarks to follow will quite probably also apply in those districts.

The symptoms manifested by different kinds of fruit trees vary considerably with respect to this trouble.

Most plums, peaches, and apricots show a very decided yellowing of the leaves, the areas between the veins being very pale green to bright yellow ; in extreme cases the smaller veins also turn yellow. Chlorotic leaves are illustrated in Plate I. Varieties differ very markedly with respect to the amount of actually yellow leaves they have, but they all agree in exhibiting a very serious rosetting with a resultant cessation of terminal growth, a formation of multiple buds, and eventually the dying back of the branches from the tips. The Gaviota plum seems to be more resistant to this chlorosis than most varieties and the Kelsey and Wickson the most susceptible. The early varieties of peaches appear to be more susceptible than the later varieties.

Apples and pears do not exhibit yellowing of leaves very often; however, in the case of apples rosetting is very marked and the leader branches die back as illustrated by an extreme case in Plate II. Pear trees do not show a rosetting, but the tips and apical leaves merely become badly scorched resulting in die-back (Plate III).

Very often half a large tree becomes affected a year or two before the other half.

The roots of trees exhibiting the above characteristics above ground appear quite normal externally.

All trees affected with this malady bear very light crops and very often no crops at all.

Soils.

The soils in which this chlorosis, rosetting and die-back occurs are nearly without exception a light sand or a very sandy loam. They are mostly very light coloured, but in some cases they may also be black with plenty of humus. The drainage is in most cases very good, and the depth of the soil is anything up to thirty or forty feet. The reaction of the soil is invariably acid, the pH being in the vicinity of 5.5—6.5.

Most of the soils are decidedly poor from a fertility point of view, but the particular grower on whose farm most of this work was done, practises a very heavy fertilizer programme along with an annual leguminous cover crop.

Rootstocks.

Very little is known as yet with regard to the susceptibility of different rootstocks to this chlorosis, but peach and plum trees whether on Myrobolan plum or on peach (probably Muir) stock, are apparently equally susceptible.

Pears when on imported French pear stock (*Pyrus communis*) are subject to this malady, and so are apples grafted on Northern Spy.

The question of the influence of the rootstock on the susceptibility to chlorosis of plum scions is under investigation.

INVESTIGATIONAL.

This work was commenced in late mid-summer in January, 1929 when soil samples and samples of plant material were first collected.

Sampling Technique.

The soil samples were taken by using a soil sampling tube or a post-hole auger. The first, second and third foot samples were kept separate. The soil from a large number of holes and from the same depth was brought together, thoroughly mixed and then a sufficient amount placed in glass containers in which the samples were sent to the laboratory.

Leaf, bark, wood and root samples were taken in the orchard and immediately placed into airtight glass containers. They were then sent to the laboratory where the moisture determinations were made within 24 hours of the time of picking. Leaf samples were divided into upper middle and lower leaves, according to their position on the current season's growth. Bark and wood samples were brought intact to the laboratory in glass jars where the bark was peeled from the wood and determinations made on them separately. Any one sample of leaves, wood or bark was made up of material from approximately twenty trees and about two dozen branches from each tree.

Soil Analysis.

The soil samples were first air dried, then passed through a 20 mesh sieve and a chemical analysis made on the fine part which had passed through the sieve. A 1 : 2 water extract was made of the soil by placing the necessary amounts of soil and water in a large bottle, shaking thoroughly for five minutes, allowing to stand for forty minutes and then filtering by suction through a porcelain filtering candle.

The analytical methods used for the various constituents in the soil extract and in the plant material were as follows :—

Calcium as calcium oxalate titrated against $KMnO_4$.

Magnesium as $MgNH_4PO_4$ and titrated against standard acid.

Potassium as Potassium Cobalti-nitrite.

Iron by a slight modification of the colorimetric method of Marriott & Wolf (29).

Manganese by a modification of the colorimetric method using sodium bismuthate as oxidizing agent (6).

Copper by the Biazzo method as described by Elvehjem & Lindow (11).

Phosphate by a modification of the colorimetric method by Atkins (3).

Sulphate as $BaSO_4$ and Chlorine as AgCl.

Nitrate by the Devarda alloy distillation method, and total Nitrogen by the Kjeldal method.

pH was determined both colorimetrically and with the quinhydrone electrode.

TABLE I.

Inorganic Constituents in a 1 : 2 *water Extract of Soil.*

Origin of Soil.		Cl.	NO_3.	SO_4.	PO_4.	Ca.	Mg.	K.	Fe.	Mn.	Cu.	pH.
From a Normal Orchard*	1st ft.	p.p.m. 16·0	p.p.m. 28·9	p.p.m. 75·0	p.p.m. 0·4	p.p.m. 29·6	p.p.m. 11·1	p.p.m. 17·1	p.p.m. ·097	p.p.m. ·033	p.p.m. ·037	6·7
From a Normal Orchard*	2nd ft.	8·0	16·5	35·8	0·25	10·6	13·4	12·3	·79	·035	·036	5·4
From a Normal Orchard*	3rd ft.	5·3	12·4	23·6	<0·05	10·3	13·9	14·5	trace	·022	·037	5·4
From a Chlorotic Orchard*	1st ft.	2·7	12·4	50·1	1·0	24·3	11·2	15·2	·075	·023	·038	6·7
From a Chlorotic Orchard*	2nd ft.	3·3	4·1	25·9	0·3	11·0	13·2	13·0	·075	·021	·035	6·2
From a Chlorotic Orchard*	3rd ft.	2·7	trace	8·8	<0·05	5·2	13·7	11·6	trace	·010	·035	5·8

* The normal and chlorotic trees are actually in the same orchard but about 75-25 yards apart.

The fairly high concentration of Calcium and of Sulphate in Table I is due to a heavy application of Gypsum. This had been applied to the soil by the owner on the advice of somebody who considered the trouble was due to black alkali or Na_2CO_3 in the soil.

No very striking difference in the two soils is brought out by the above table. This is to be expected when the proximity of the soils is taken into consideration. As a matter of fact it can only be a question of time before the trees in the normal orchard will also become chlorotic ; evidence of this can already be detected in scattered trees throughout the normal orchard.

The reaction of both soils is on the acid side.

The replaceable bases were also determined on the above soils by using the NH_4Cl method described by Kelly and Brown (22). Table II shows these results.

TABLE II.

Replaceable bases (expressed as p.p.m. of the dry soil) in soils from Chlorotic and from Normal Orchards.

Origin of Soil.		Ca.	Mg.	K.	Fe.	Mn.	Cu.
Normal Orchard ..	1st ft.	1440·0	88·0	179·0	8·6	6·6	2·9
Normal Orchard ..	2nd ft.	640·0	64·0	134·3	9·3	4·2	—
Normal Orchard ..	3rd ft.	356·0	56·0	94·6	11·6	3·4	2·3
Chlorotic Orchard ..	1st ft.	727·0	64·0	106·3	8·0	7·5	2·8
Chlorotic Orchard ..	2nd ft.	240·0	72·0	87·0	7·0	2·7	3·0
Chlorotic Orchard ..	3rd ft.	93·0	32·0	81·6	19·6	1·6	—

The relatively large amounts of Ca shown in Table II for the surface soils are no doubt due to a solubility effect more than a base replacement ; the large quantities of $CaSO_4$ which had been applied to the surface soil had apparently not yet moved down into the subsoil.

The potassium content of the above soils is low as would be expected in a poor sandy soil which has been derived from sandstone. The application of potassium would no doubt be advisable from a nutritional point of view but such applications had no effect on the chlorosis.

There are no striking differences between the two soils except perhaps the smaller amounts of Mn in the subsoils from the chlorotic orchards.

Analyses of Material.

As stated before, the first samples of plant material were taken for analysis in late mid-summer 1929, and the results are shown in Table III.

TABLE III.

Analyses of Leaves, Wood and Bark from Chlorotic and Normal Kelsey Plum Trees on Myrobolan Stock.

(*Results are expressed on basis of dry material*).

mple No.	Description of Sample.	Moisture.* %	Ash. %	Cl.	N.	SO$_4$.	PO$_4$.	Ca.	Mg.	K.	Fe.	Mn.	Cu.
				p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
	Top leaves, chlorotic	71·8	10·56	1700·0	27000·0	5761·4	15·9	9450·0	5490·0	28349·0	370·3	10·0	3·2
	Top leaves, normal	63·7	8·85	1800·0	24000·0	4976·7	21·2	9200·0	3660·0	23817·0	250·0	17·1	7·3
	Middle leaves, chlorotic	70·6	12·34	1700·0	22000·0	4873·4	52·1	13100·0	4040·0	33435·0	357·2	14·7	2·9
	Middle leaves, normal	62·7	9·15	1900·0	21850·0	5100·6	30·0	12050·0	3210·0	27673·0	312·5	16·6	4·6
	Lower leaves, chlorotic	68·1	14·28	2000·0	23200·0	4212·6	54·6	23750·0	5040·0	33726·0	416·6	25·5	3·5
	Lower leaves, normal	62·7	10·83	2900·0	24300·0	5018·0	23·3	15850·0	2940·0	30803·0	330·2	19·5	6·9
B.	Bark, current season, chlorotic ..	68·5	10·84	1500·0	11000·0	1171·4	56·8	34300·0	2640·0	14942·0	87·4	24·03	10·00
B.	Bark, current season, normal ..	70·6	8·60	1500·0	9125·0	1644·0	75·8	23300·0	2280·0	20346·0	80·2	36·46	10·26
W.	Wood, current season, chlorotic ..	58·4	1·59	2500·0	3350·0	348·7	<5·0	2334·0	816·0	6224·0	115·1	2·79	4·54
W.	Wood, current season, normal ..	60·5	1·03	2400·0	2700·0	679·2	<5·0	1600·0	776·0	8643·0	44·4	4·12	5·00
B.	Bark, one year old, chlorotic ..	59·3	7·97	2650·0	8936·0	849·0	19·5	26100·0	1620·0	7967·0	121·2	31·69	10·00
B.	Bark, one year old, normal ..	61·7	5·39	2900·0	9380·0	557·7	74·2	15180·0	1224·0	7846·0	102·5	61·86	11·54
W.	Wood, one year old, chlorotic ..	44·0	0·57	850·0	2400·0	392·7	<5·0	1416·6	180·0	1120·0	43·3	2·60	3·23
W.	Wood, one year old, normal ..	44·5	0·44	2050·0	2100·0	200·9	<5·0	933·3	140·0	1333·0	36·2	3·47	5·51
B.	Bark, two years old, chlorotic ..	56·4	5·73	2100·0	6700·0	506·9	47·6	20500·0	1200·0	4944·0	175·4	30·41	11·54
B.	Bark, two years old, normal ..	59·1	4·73	2100·0	8850·0	739·8	55·5	15500·0	1224·0	5122·0	144·4	47·62	11·76
W.	Wood, two years old, chlorotic ..	46·0	0·45	2100·0	2000·0	127·9	<5·0	1333·3	200·0	898·0	36·8	2·31	3·57
W.	Wood, two years old, normal ..	45·9	0·31	600·0	1670·0	214·8	<5·0	933·3	188·0	907·0	39·6	3·08	2·59
B.	Bark, three years old, chlorotic ..	53·7	5·30	3750·0	7370·0	548·0	8·5	19150·0	1200·0	4695·0	148·2	27·78	6·66
B.	Bark, three years old, normal ..	57·9	3·54	3600·0	8350·0	561·7	17·4	13800·0	1284·0	5264·0	131·5	48·61	10·00
W.	Wood, three year old, chlorotic ..	45·6	0·56	700·0	2000·0	109·6	<5·0	1333·3	240·0	782·0	52·1	2·41	5·95
W.	Wood, three years old, normal ..	45·6	0·37	500·0	1675·0	210·1	<5·0	866·7	160·0	1005·0	41·7	3·14	3·26
B.	Bark from roots, chlorotic ..	—	2·22	—	—	191·8	—	9150·0	960·0	2596·0	70·9	5·85	4·30
B.	Bark from roots, normal	—	5·21	—	—	328·8	—	17050·0	1020·0	5299·0	122·9	7·04	5·63
W.	Wood from roots, chlorotic ..	—	0·60	—	—	301·4	—	1116·7	400·0	1116·0	56·5	3·12	3·19
W.	Bark from roots, normal ..	—	0·95	—	—	246·6	—	1216·7	240·0	1587·0	113·6	2·34	4·17

* The moisture is expressed as a percentage of the moist material.

The object of the analyses presented in Table III was to try to find out which element (or elements) was present in deficient amounts in chlorotic trees and, if successful, then to trace how far down from the leaves this deficiency could be detected in the tree. Samples were accordingly taken as indicated in the table and by using the sampling technique described above.

The results of the analyses of the leaves show a decided increase in concentration from the young to the old leaves. This is particularly illustrated by the percentage of ash and the K, Ca, PO_4 and Cl contents.

The concentration of inorganic elements in the bark and wood, on the other hand, decreases from the younger growth to the older growth, the percentage of ash and the concentration of K, Ca, and SO_4 being particularly significant.

With regard to the differences in concentration of the various elements in chlorotic and normal material it will first be observed that the ash content of the material taken from the aerial parts of chlorotic trees is always considerably higher than that from normal trees ; this, no doubt, is partly due to less carbohydrates being synthesized in the former. The same relationship in ash contents was found in the case of lime-induced chlorosis by Wallace (46) and Wallace and Mann (50). This difference in ash content is consistently reflected in the concentrations of Ca and Fe in all aerial parts of the tree and in the K content of the leaves. In contrast to the Ca, Fe and K which is present in greater quantities in the chlorotic than in the normal material and also in contrast to most of the other ions where this relationship is indefinite, the content of Mn and Cu in chlorotic material is nearly consistently less than that found in the normal material. This is even more strongly brought out when the Mn and Cu figures are expressed on the ash basis as in Table IV.

Analyses of Fruit and Seeds.

As there was a possibility that the fruit harvested from chlorotic trees, even though the crops were small, might, when mixed with the rest of the crop from normal trees, cause wastage during transport and storage if the former has been adversely affected by the chlorotic condition of the trees, it was decided to store some fruit from chlorotic and from normal trees. The results from storage at room temperature or in cold store however, showed no noticeable difference in the fruit from the two sources.

Analyses were then made of the fruit, separating the flesh of the fruit from the seed and also the shell or testa from the kernel. The results of the analyses are shown in Table V. One hundred Kelsey plums were used for each composite sample from which aliquots were taken for the various analyses.

The remarks on the analyses of the leaf, wood and bark material also largely hold for the fruit and seed. The ash content, except in the case of the flesh, is considerably higher in the chlorotic material than in the normal and is principally

TABLE IV.

Mn and Cu content of Chlorotic and Normal Material when expressed on Ash Basis.

Sample No.	Description of Sample.	Mn.	Cu.
		p.p.m.	p.p.m.
1	Top leaves, chlorotic	94·7	30·3
2	Top leaves, normal	193·2	82·5
3	Middle leaves, chlorotic	119·1	23·5
4	Middle leaves, normal	181·4	50·3
5	Lower leaves, chlorotic	178·6	24·5
6	Lower leaves, normal	180·1	63·7
7 B.	Bark, current season, chlorotic	221·7	92·3
8 B.	Bark, current season, normal	423·9	119·3
7 W.	Wood, current season, chlorotic	175·5	285·5
8 W.	Wood, current season, normal	400·0	485·4
9 B.	Bark, one year old, chlorotic	397·6	125·6
10 B.	Bark, one year old, normal	1156·3	215·7
9 W.	Wood, one year old, chlorotic	456·1	566·7
10 W.	Wood, one year old, normal	788·6	1252·3
11 B.	Bark, two years old, chlorotic	451·9	171·5
12 B.	Bark, two years old, normal	1006·8	248·6
11 W.	Wood, two years old, chlorotic	513·3	793·3
12 W.	Wood, two years old, normal	993·6	835·4
13 B.	Bark, three years old, chlorotic	524·2	106·8
14 B.	Bark, three years old, normal	1373·2	282·5
13 W.	Wood, three years old, chlorotic	430·4	1062·5
14 W.	Wood, three years old, normal	848·7	881·1
15 B.	Bark from roots, chlorotic	263·5	100·0
16 B.	Bark from roots, normal	135·1	108·1
15 W.	Wood from roots, chlorotic	520·0	531·7
16 W.	Bark from roots, normal	246·3	439·0

reflected in the Ca, Mg and N concentrations. The trend of figures for Mn is not striking like those in Table III but the Cu content is again consistently lower in the chlorotic material than in the normal. Though the copper content of the kernels from the two sources is the same when expressed on the dry basis the difference is still considerable when expressed on the ash basis.

The accumulation of all the ions except Cl and K in the kernels is noteworthy, but the tremendous accumulation of Cu is remarkable ; this accumulation of Cu in the case of the kernels from a chlorotic source has nearly reached that obtained in the kernels from the normal trees which have a higher Cu content throughout.

REMEDIAL MEASURES.

All the above analytical work points to two explanations for this chlorotic condition, namely a possibility of a manganese deficiency and a probability of a copper deficiency. Nearly all efforts were accordingly directed to the application of Mn and Cu to the trees. To save much useless description it may be said at the outset, however, that all methods of application of Mn proved without any influence whatsoever on the chlorotic condition of the trees ; the same applies

TABLE V.

Results of Analyses of Fruit and Seeds expressed on Dry Basis.

Description of Sample.	Moisture* %	Ash. %	Cl.	N.	SO_4	PO_4	Ca.	Mg.	K.	Fe.	Mn.	Cu.
			p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Flesh of Fruit from Chlorotic tree ..	85·5	2·74	248·2	7200·0	2575·4	498·9	547·3	1,103·2	14,153·1	76·6	7·1	1·7
Flesh of Fruit from Normal tree ..	84·6	2·82	248·0	6750·0	1130·8	389·8	378·9	783·2	15,950·3	53·9	7·4	2·2
Testas of seeds from Chlorotic tree ..	30·8	0·55	35·5	2400·0	184·9	201·5	842·1	1,162·1	2,695·8	7·3	15·6	1·8
Testas of seed from Normal tree ..	31·5	0·30	35·5	2000·0	61·7	201·5	547·3	454·7	3,369·8	14·3	9·1	2·5
Kernel of seed from Chlorotic tree ..	42·2	4·10	36·0	34000·0	5273·1	526·2	3915·8	4332·6	11,307·5	114·4	25·6	12·5
Kernel of Seed from Normal tree ..	42·8	3·50	36·0	31780·0	5480·7	498·9	2547·3	4,130·5	11,443·2	128·3	27·7	12·5

* The moisture is expressed as a percentage of the moist material.

also to Mg, K, Fe, S and manure which were tried arbitrarily because their insufficiency has been shown to cause a chlorotic condition in plants in different parts of the world. All further remarks will now be limited to those tests carried out with copper.

Spraying.

Spraying with Bordeaux Mixture or with a commercial colloidal copper was entirely unsuccessful and spraying with $CuSO_4$ solution was impracticable because of its toxicity and danger of scorching the leaves.

Injection.

Two litres of a dilute solution of $CuSO_4$ containing 0.3 p.p.m. Cu were injected into the trunk of each tree by the method originated by Sachs (40) only using glass and rubber connections. The amount of copper absorbed by a tree in this way was presumably too small because no beneficial effects resulted.

The dry salt or plugging method described by Mokrzecki (35) could not be applied in the case of $CuSO_4$, again because of its toxicity, but a few trees were tried with a very slightly soluble copper salt such as $CuCO_3$. In the few cases experimented with no beneficial effects were noticed.

Leaves Dipped in Cu solutions.

Test tubes filled with a solution of $CuSO_4$ of 0.3 p.p.m. Cu were fixed to trees with strips of adhesive tape and a chlorotic leaf was bent so as to dip into the solution in each tube. As controls test tubes containing distilled water were used. After two weeks the particular leaves which had been immersed in the $CuSO_4$ solution had turned perfectly green whereas the rest of the leaves on the same twig were still chlorotic. Plate IV illustrates such a twig where only the one leaf has turned green. Occasionally the whole twig may turn green.

Soil Treatment in the Field.

Young plum trees just planted and trees up to ten years old were treated by scattering amounts of $CuSO_4$ varying from $\frac{1}{4}$ to 2 lb. per tree on the soil and digging or ploughing it in. The best time to do this is in early winter and partial or complete recovery of the trees took place during the following summer, depending upon the state the tree was in when treated. Recovery was always evidenced by a tremendous increase in shoot growth and in most cases also a complete greening up of the leaves ; however, it was noticed especially with young Kelsey plum trees that, though the vigour of the tree was always greatly improved and rosetting had completely disappeared the first year, there may still be some yellow leaves on the trees.

Trees so treated and cured are shown alongside untreated trees on Plates V, VI, VII, VIII and IX.

Instead of applying the $CuSO_4$ to the soil by the above method in early winter so that the winter rains can wash the $CuSO_4$ down to the root zone, the same effect was procured more quickly by injecting the CuSO as a suspension or a solution 2-3 feet into the soil by the injection apparatus described by McKinnon and Lilleland (27). This could be done in early spring and still bring about the desired effect the following summer.

Greenhouse Experiments.

Large quantities of surface soil (top 18 in.) and of subsoil (second 18 in.) were railed in bags from a chlorotic orchard to the laboratory in Cape Town, about 100 miles away. Here the two soils were kept separate but each was thoroughly mixed so as to get it as homogeneous as possible, and then a large number of unglazed earthenware pots were filled with the surface soil and a similar number with the subsoil. Young Kelsey plum seedlings which had been procured by germinating seed from plums harvested separately from normal and from chlorotic trees growing in the same orchard from where the soil had been brought were then planted in the potted soils. Some of the pots were treated with $CuSO_4$ at the rates of 100 and 200 lb. per acre with or without nitrogen, the rest of the pots acted as controls, also with or without the application of N. After eighteen months, at the time of writing this report, though there were indications that the trees treated with copper had grown a little better than the controls, none of the trees had yet shown a very decided chlorotic condition. This rather surprising non-appearance of chlorosis is probably due to changes having taken place in the soil due to the totally different locality, and also to the relatively large amounts of Cu which accumulate in the kernels of fruit (Table V).

Similar pot trials to the above were also carried out with spinach and oats and the stimulation caused by the application of Cu was very marked indeed, although no chlorosis was evident. This stimulation is no doubt similar to the effect produced with Cu on various plants by other investigators (24, 36).

ANALYSES OF SOILS AND PLANT MATERIAL AFTER TREATMENT WITH $CuSO_4$.

Samples were taken from plots and trees which had been cured by the application of $CuSO_4$ to the soil and the result of the analyses are compared in the following tables with those from the control plots taken on the same day.

TABLE VI.

Copper in Treated and Untreated Soils.

Origin of Soil.	1 : 2 Water Extract. p.p.m.	1 : 2 Water Extract at 70°C.* p.p.m.	Replaceable Copper. p.p.m of dry soil.
Untreated Soil :			
1st ft. ..	·0417	·0421	1·78
2nd ft.	·0342	·0296	2·74
3rd ft.	·0370	·0353	1·78
¼ lb. $CuSO_4$ per tree :			
1st ft. ..	·0526	·0714	3·72
2nd ft.	·0556	·0381	3·32
3rd ft.	·0686	·0645	2·86

* This extract was made to ensure that the very slightly soluble Cu-compounds were not being included with the replaceable Cu.

Leaf samples from tips of the current season's growth were taken from chlorotic untreated trees, from trees cured by the application of ¼ lb. of $CuSO_4$ to the soil and from trees which had been cured by transplanting two years previously from the chlorotic orchard to a totally different soil about a mile distant. The results are shown in Table VII.

TABLE VII.

Copper Content of Leaves of Chlorotic and of Cured Trees.

Sample.	Copper p.p.m.
Top leaves. Chlorotic Kelsey Plum on peach stock	4·25
Top leaves. As above, but cured by application of ¼ lb. $CuSO_4$	7·17
Top leaves. As above, but cured by transplanting to different soil	9·52

It is clear from the above results that the treatment of the soil with $CuSO_4$ are distinctly reflected in the Cu content of the water extract as well as in the amount of replaceable copper in the soil. The trees which have been cured also show a much increased amount of copper in the leaves.

CONCLUSIONS.

From the foregoing it is obvious that the chlorotic condition described herein is due to a deficiency of copper in the plants and that the malady can be cured by the application of copper sulphate to the soil in amounts from ¼ to 2 lb. per tree. Such applications of copper sulphate are then reflected in an increased copper content of the leaves.

DISCUSSION.

The very close relationship that exists between haemoglobin in the animal and chlorophyll in plants has been referred to by many investigators. Raber (37) has shown that by treating haemoglobin and chlorophyll with an acid and then an alkali the respective porphyrins—hematoporphyrin and phylloporphyrin are formed which differ only slightly in the amount of oxygen contained. He found a further relationship between the two substances by checking the yellowing of plants under etiolation conditions by adding liver extract (which substance is successfully used to check pernicious anaemia in animals), to the culture solution.

Preliminary experiments were conducted here much on the same lines as reported by Raber with liver extract, with the object of ascertaining whether copper has any effect on chlorophyll formation or rather whether copper plays a part in protecting the chlorophyll from being destroyed. Wheat seedlings were grown in distilled water until the second leaf had started to develop ; then they were transferred to jars of Hoagland's complete culture solution of which one set of jars contained 0.3 p.p.m. Cu in the form of $CuSO_4$. The plants were then left to grow for ten days in the light, after which they were all placed in a dark cupboard. On removal of the plants from the dark after a week the set to which the copper had been added were distinctly greener than the set without copper. It is very probable, then, that the similar effect procured by Raber when using liver extract in the culture solution was due to the presence of copper which is always present in liver. What the mechanism of the copper is in this case is hard to tell and will require considerable more experimentation, but it somehow seems to protect the chlorophyll from being destroyed, possibly in much the same way as liver extract is considered by many animal physiologists to protect the haemoglobin from destruction rather than to stimulate the regeneration of haemoglobin in cases of pernicious anaemia in animals.

Another similarity between chlorophyll and haemoglobin is illustrated in this paper by the chlorotic condition of the trees which can be cured by the addition of copper, and the large number of investigations reported where nutritional anaemia in animals is readily overcome when minute amounts of copper are added to the diet along with iron (10, 26, 8, 20, 34, 43).

The minute amounts in which copper is essential for normal plant growth would indicate that its function in the plant is that of a catalyst. It has been shown by Voegtlin, Johnson and Rosenthal (44) that of all the heavy metals studied, only copper caused an acceleration of the oxidation of crystalline glutathione and they postulate the mechanism of oxidation to be a reaction between the cupric ion and the -SH group with the formation of a cuprous glutathione complex readily oxidizable by molecular oxygen. This action of copper as an autoxidant is of particular interest here as both glutathione and copper are known to be present in plants.

The tremendous catalytic effect of Cu in the oxidation of cysteine has been shown by Elvehjem (9) and such great activity indicates the possible radical disturbances that could be caused in a plant if the essential amount of copper was either not present or conditions were such that it could not fulfil its functions.

SUMMARY.

1. A chlorotic, rosetting and die-back condition of deciduous fruit trees growing in a sandy, well drained soil of acid reaction is described.

2. Treatment with K, Mg, Mn, S, Fe or manure had no effect on the malady.

3. Analyses of plant material showed a consistent deficiency of copper in the chlorotic trees, which could be traced from the leaves and fruit down to three year old bark and wood and to the roots. The ash content of the chlorotic material is always much higher than that of normal material.

4. Applications of Cu in the form of $CuSO_4$ to the soil in amounts from $\frac{1}{4}$ to 2 lb. per tree were successful in curing the chlorotic condition. Such applications to the soil are reflected in the copper content of the leaves.

5. Leaves dipped in very dilute solutions of copper sulphate turned green within two weeks.

ACKNOWLEDGMENTS.

In conclusion I wish to express my appreciation of the very thorough and conscientious way in which Mr. A. J. v. d. Merwe, B.Sc. assisted me with the analytical work herein recorded. Also thanks are due to the Co-operative Deciduous Fruit Exchange of South Africa who, by a grant, made it possible to procure Mr. v. d. Merwe's valuable services.

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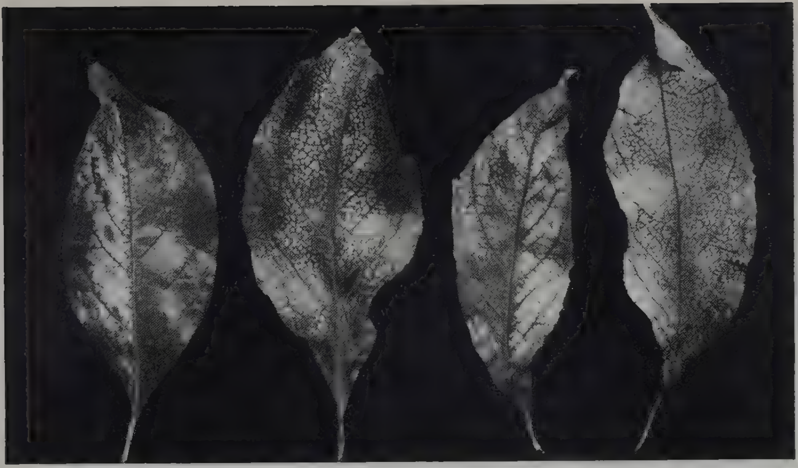
(*Received* 26/5/32.)

BOOK REVIEWS.

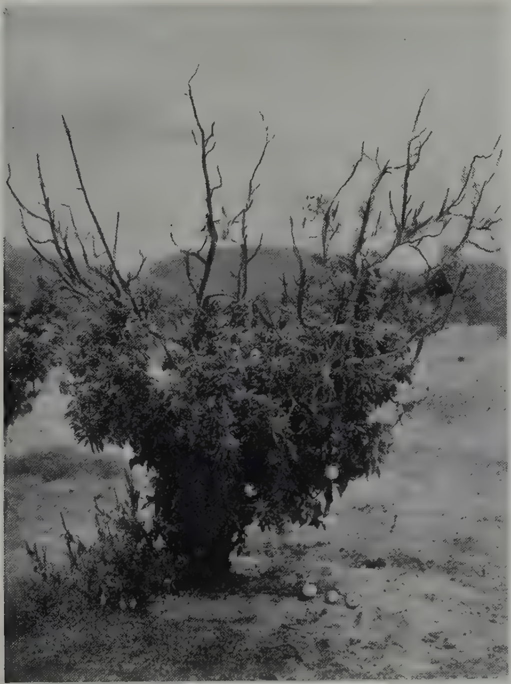
"Horticultural Abstracts," Vol. I, and "Fertilizers and Food Production on Arable and Grass Land," by Sir Frederick Keeble, C.B.E., Sc.D., F.R.S., have been received for review and will be given notice in the next number.

PLATE I.



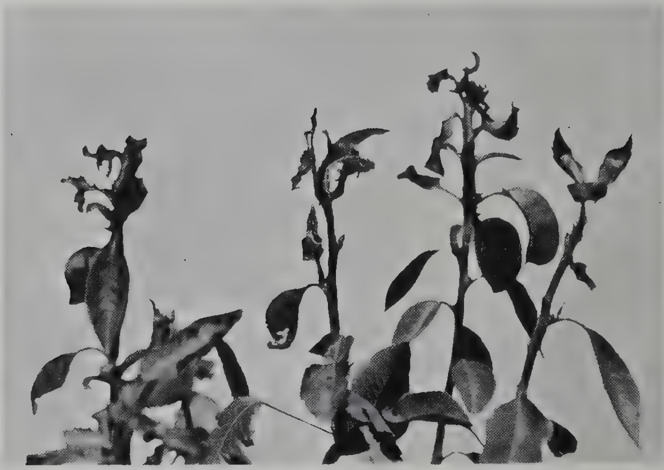
Mature chlorotic plum leaves; younger leaves appear more like those on Plate IV.

PLATE II.



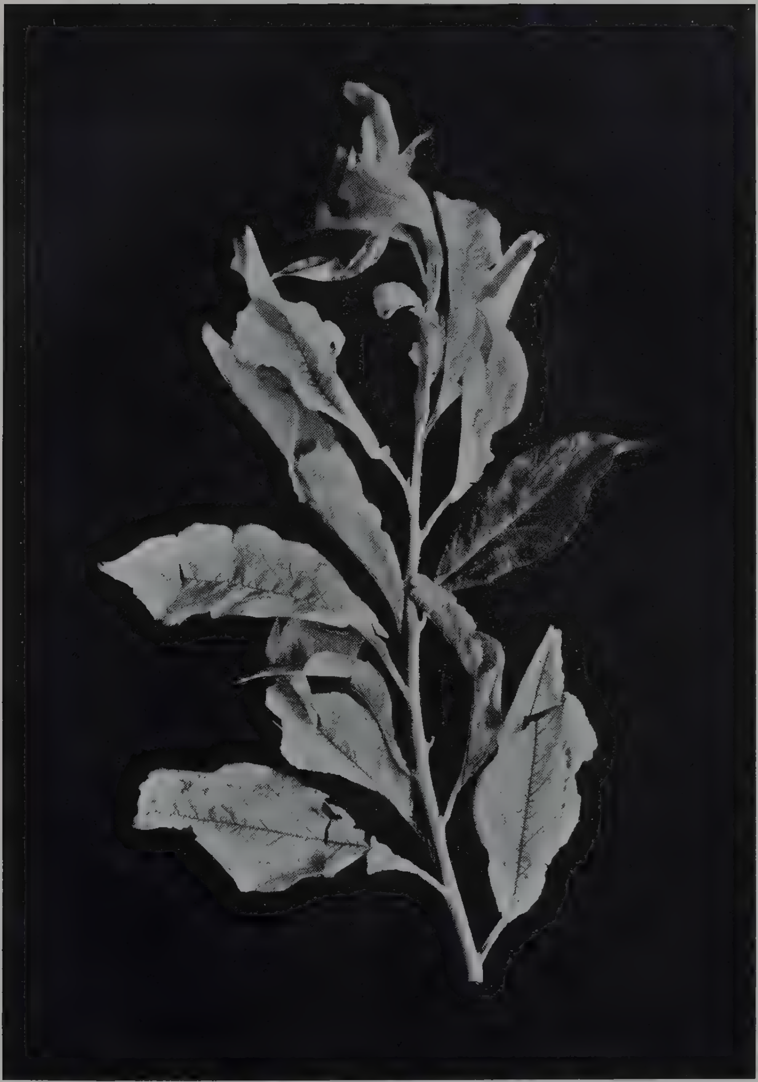
An advanced stage of die-back and rosetting in a ten-year-old apple tree.

PLATE III.



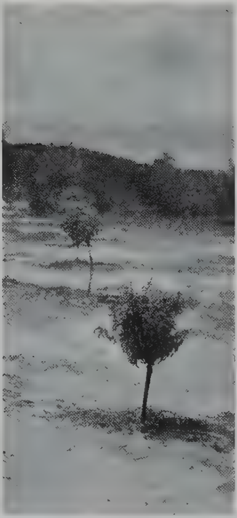
Scorching and die-back of terminals of a pear tree.

PLATE IV.



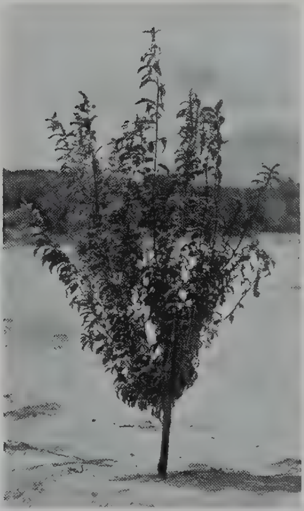
The single green leaf on an otherwise chlorotic twig has been made so by ten days immersion in a solution containing 0·3 p.p.m. Cu.

Plate V.



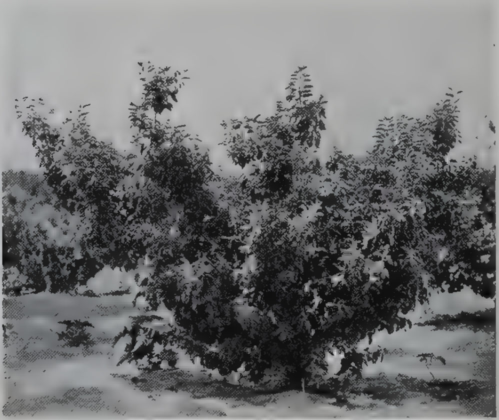
A Kelsey plum tree in its second leaf. Chlorosis and rosetting very severe.

Plate VI.



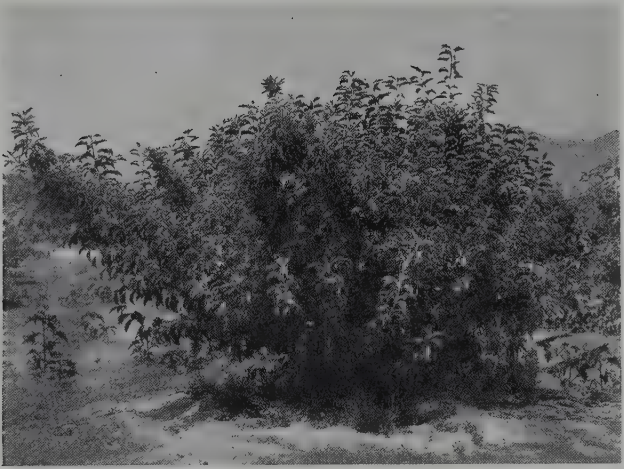
The tree next to that in Plate V, and in the same row, but treated with ½ lb. $CuSO_4$ sixteen months previously.

Plate VII.



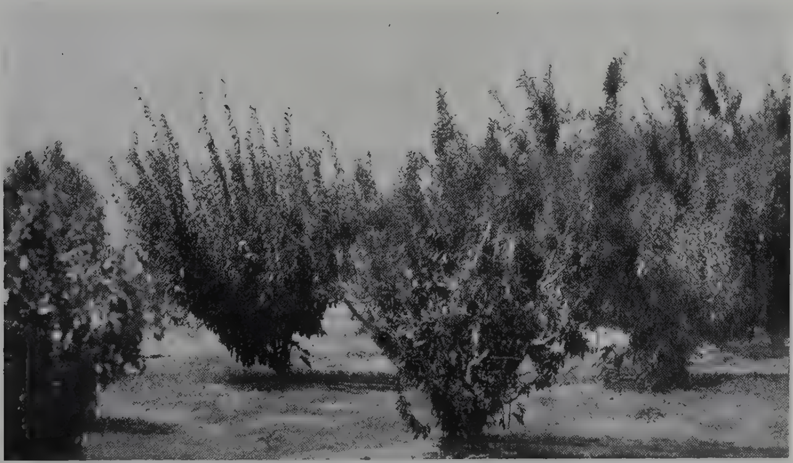
Chlorosis and rosetting in a ten-year-old apple tree. Note lack of terminal growth.

PLATE VIII.



The tree next to that in Plate VII and in the same row, but treated with 1 lb. $CuSO_4$ sixteen months previously. Note increased terminal growth.

PLATE IX.



Ten-year-old Kelsey plum trees. In the foreground a tree badly affected with chlorosis and die-back. In the background a similar tree but after treatment with ½ lb. $CuSO_4$ two years previously. Note increased terminal growth.

THE EFFECTS OF VARIOUS MANURIAL TREATMENTS ON THE CHEMICAL COMPOSITION OF STRAWBERRIES.

By LUCY. D. M. KNIGHT AND T. WALLACE,
Long Ashton Research Station, University of Bristol.

It has been the general experience of investigators who have carried out experiments on the effects of fertilizer treatments on strawberries that the plant is one of the most difficult with which to obtain results giving very clear indications of the effects of the various treatments tested.

The difficulties have been emphasized by Bedford and Pickering (1) and Dyer and Shrivell (7) in this country, and by Chandler (4) in U.S.A., in all instances after considerable experience in fertilizer experiments with various kinds of fruit plants.

Not only have effects on plant vigour and fruit yields been difficult to assess owing to the variability of results due to inherent variability of the plants and seasonal and other causes, but the effects on the quality of the crops, a very important point in strawberry culture, have remained practically undetermined.

In view of this lack of knowledge, an attempt is being made at Long Ashton to elucidate some of the effects of fertilizer treatments and, in order to do this, field experiments have been laid down to provide material for studies relating to growth and cropping and to quality factors of the crop.

The complete results concerning the effects of the manures on field characters such as growth and crop yields will not be available for a number of years, since it seems unsafe to generalize from the results of a few seasons, and it is also intended in the experiments to determine the effects of continuous cropping of the plots with strawberries under the different nutrient treatments over a substantial period of years. This latter point is of considerable importance commercially, since strawberries are largely grown by small holders on comparatively small areas where it is impossible to follow crop rotations to any extent, and the opinion is widely held that land continuously cropped with strawberries becomes " strawberry sick ".

As a part of the proposed programme of investigations relating to fruit quality, a study was made of various chemical characters of the 1931 crops from certain plots, attention being given to two main points:—

1. The changes in chemical composition which occur during the picking season.

2. The effects of differential manurial treatments on the contents of total nitrogen, acidity, total sugars, reducing sugars, sucrose, total ash and certain ash constituents.

It seemed desirable to investigate 1, since it is known that the quality of the berries shows a well marked continuous change over the picking season, early fruits being relatively large and pre-eminently suited for dessert purposes whilst late fruits are smaller and possess special jamming qualities. In view of such changes, it seems probable that any effects which the manures might exercise on chemical composition might vary in magnitude over the season or only be apparent at a definite part of the picking period.

The results obtained in the investigation have shown that certain chemical constituents of the fruits vary over the picking season whilst others show no clear changes, and that the different manurial treatments considered are reflected in the composition of the fruits. In particular, potassium deficiency is clearly shown in cases where potassic manures are not applied and, although differences cannot be distinguished in the field between "potash omitted" and "no manure" plots, the differential treatments are reflected by certain chemical features.

HISTORICAL.

In this country, the only experiments of note which have been conducted on the manuring of strawberries have been carried out by Bedford and Pickering at Woburn (1) and by Dyer and Shrivell at Hadlow, Kent (7). The results at both centres referred mainly to the effects of the manurial treatments on yields, and little attention was given to quality of the berries other than to size and firmness.

The Woburn results may be summarized as follows:—

> Manures as a whole, i.e. averaging the effects of dung and artificials, showed an increase of 12 per cent; dung gave somewhat larger increases than artificials, approximately 8 per cent, improved the size and quality of the berries and increased the longevity of the plants; dung at 30 tons per acre increased the yield over dung at 12 tons per acre by 10 per cent; manuring did not affect the date of ripening, the dates of the first pick or the length of the picking season.

Pickering, in reporting the results, referred especially to the lack of substantial increases from manuring, either from dung or artificials, in the experiments, and to the manner in which the strawberry plant is affected by slight changes in environment apart from manuring.

Dyer and Shrivell carried out tests from 1895-1911 with five different plantings and using three varieties, President, Paxton and Royal Sovereign, in each experiment crops being taken so long as the beds remained in fair commercial condition. Altogether nineteen crops were harvested so that the tests may be regarded as really extensive.

The treatments included dung at light and heavy rates, dung supplemented with complete artificials and artificials less potash, and complete artificials alone and less potash.

The main results which emerged were as follows:—

1. Potash salts in the earlier years appeared harmful when used with dung.
2. Potash omission, when dung was not given, severely decreased crops in the later years of the experiments.
3. Light dressings of dung supplemented with moderate dressings of nitrogen and phosphorus produced slightly earlier crops.
4. Dung alone was much superior to artificials in increasing yields.

As a result of the experiments, the recommendation was made that the best effects would probably be obtained from light annual dressings of dung, 12-13 tons per acre, supplemented with annual dressings of nitrate of soda at 2 cwt. per acre and superphosphate at 5 cwt. per acre.

Chandler (4) has summarized some of the earlier experiments in the U.S.A. in Missouri, Hood River Valley, Oregon, and New York State, and in these most emphasis appears to have been placed on the effects of nitrogenous dressings. Nitrogen appeared to exert harmful effects in the Missouri experiments whereas in Oregon it produced increased yields.

In New York the results were rather contradictory, though the results suggested favourable effects from phosphorus and potassium in some cases. Chandler, after reviewing the main features of the results, regards the evidence relating to manurial effects on strawberries as unsatisfactory.

More recently, further results of fertilizer experiments have been reported by Wentworth (26), Greve and Shoemaker (9), Taylor (20), and Kimbrough (11).

Wentworth, in New Hampshire, examined the effect of dressings of nitrate of soda in two plantings and concluded that, although the fertilizer increased the amount of foliage, crop yields were more often reduced than increased.

Greve and Shoemaker reported increased yields from both late summer and early spring applications of nitrate and noted the following effects of the fertilizer treatments on the quality of the berries: they were slightly less firm as judged by pressure tests but shipping quality was not appreciably affected; nitrogen content and catalase activity were increased; lower percentages of total sugars and reducing sugars resulted; and pH value was decreased (i.e. acidity was increased).

Taylor observed the effects of winter applications of nitrate of soda under the early conditions obtaining in Alabama. The extra nitrogen dressing was applied to portions of plots which had received previous applications of nitrogen, phosphorus and potash. The nitrate dressings resulted in increases in the following features: plant size, numbers of blossoms and berries, total weight of No. 1 grade fruits, berry size and number of runners formed. Percentage set was not significantly affected. It was also found that superphosphate was beneficial to general vigour but potash dressings produced no visible effects.

Kimbrough, in Louisiana, attempted to assess the effects of rainfall, soil moisture and fertilizer treatments in two years, in one of which rainfall was very high during the fruiting season and in the other when climatic conditions were exceedingly dry. Chemical features of the crop, moisture content and total and reducing sugars over the picking season and in relation to the above factors were examined.

The following conclusions were formed:—

In the wet season of 1928, rainfall and time of harvesting produced greater effects on the chemical characters than the fertilizer treatments.

In 1930, when drought conditions prevailed, berries on unfertilized plots were small and of relatively high water content, and had lower sugar contents than berries on the fertilized plots.

Moisture contents of the berries decreased and sugar contents increased over the picking season on unwatered plots, and time of harvesting produced greater effects on composition than the different fertilizer treatments. Heavy watering of the soil practically maintained a constant water content of the fruits over the season and the sugar contents of watered fruits were much lower than those on unwatered plots.

The results of Greve and Shoemaker and of Kimbrough thus suggest that it will be profitable to carry out chemical determinations on fruits in fertilizer experiments on strawberries, though it appears from our results that neither of these experiments have been sufficiently extensive on the chemical side.

Several investigators have previously endeavoured to determine the effects of various environmental factors on the chemical constituents of fruits, the majority of the studies having related to apples and several being in connection with storage problems. Of these, the following are of special significance in the present instance: Brown (2), Degman (6), Weinberger (25), Gourley and Hopkins (8), Magness and Overley (13), Caldwell (3), Shaw (18, 19), Nightingale, Addoms and Blake (16), Gustafson (10), Lilleland (12), Vogel and Weber (21) and Wallace (22, 23, 24).

Brown correlated high percentages of available potassium and phosphorus in soils with high percentages of these elements in apples grown on them.

Degman and Weinberger examined the effects of nitrogenous and potassic manures respectively on apples and peaches in Maryland. The effects from nitrogen were very small and from potassium in all cases negligible. Gourley and Hopkins found that nitrogenous fertilizers applied to apples greatly increased the nitrogen content and also the moisture content, slightly decreased sugar content and colour, and did not affect either respiration rate or pH of the juice. Magness and Overley studied the effects of nitrogen, phosphorus and potassium on apples and concluded that nitrogen slightly affected colour, but the effects of the other two elements were negative in character. Caldwell and Shaw carried out elaborate investigations in endeavours to relate climatic effects with quality in apples, and some of the conclusions of Caldwell are of special interest, viz:—

1. Of the climatic factors, sunshine, temperature and precipitation, sunshine and temperature produce the greatest effects and those due to sunshine are larger than those of temperature.
2. In apple juices the contents of total sugars and sucrose are positively correlated with acidity and show a negative correlation with astringency (i.e. "tannin"). The correlations may be upset to some extent by local factors, e.g. water shortage.

Nightingale, Addoms and Blake traced the changes in the composition of peaches over the ripening season in two cases, under low and high nitrogen conditions respectively, and obtained the following results:—

1. Fruits on the low N tree ripened earlier than those on the high N tree.
2. In both cases over the ripening season, the percentage of reducing sugars was irregular but increased somewhat; sucrose increased sharply in amount towards the ripening point; total sugars increased in a similar way to sucrose; total pectin, protopectin, hemi-cellulose and cellulose all decreased with ripening; nitrogen showed a gradual decrease over the period, ash decreased and acidity tended to increase to near ripening point and then decreased suddenly.
3. The high N tree produced fruits with high total nitrogen and high soluble nitrogen, high ash, and low sugars and tannin.

The results in the above paper thus show clearly both the effects of ripening and of high and low nitrogen feeding on the composition of the fruits.

Gustafson followed the changes in ash content and percentages of certain constituents in the ash of tomato fruits during the growth period to the ripening stage, the results showing the following features:—

> Ash content showed an initial fall and was later inclined to rise; calcium showed a definite but slight rise throughout; potassium exhibited a slight fall; magnesium results were indefinite and phosphorus showed slight fluctuations but was practically constant throughout.
>
> In addition, acidity showed steady increases and nitrogen gradual decreases to the ripe stage.

Lilleland compared the sugar contents of prunes from trees obviously suffering from potassium deficiency with others in which the deficiency effects had been overcome by potash manuring but was unable to detect any differences either in reducing or total sugars in the two cases. The contents of potassium in the fruits did not differ significantly, though in the leaves a large difference was evident.

The fact that Lilleland examined only the ripest specimens of fruits in each case may have masked somewhat any differences which might exist since it has been frequently observed by one of us (Wallace) that the majority of fruits on potassium deficient trees in this country remain of immature appearance.

Vogel and Weber investigated a case of leaf scorch of red currants which appeared to result from two causes, deficiency of potassium and chlorine injury following the use of large quantities of potash salts. The berries in both cases were small, lacked juice and pulp, and contained low amounts of acid and sugars and high proportions of chlorine.

Wallace (24) has reported the results of extensive chemical investigations relative to the effects of potassium deficiency on the mineral content of various parts of fruit plants, and has shown that deficiency of the element affects the proportions of dry matter in fresh weight, ash in dry matter and percentages of potassium, calcium, and phosphorus in the ash in all parts of the affected plants.

He (22) also examined the effect of various manurial treatments on gooseberries at Long Ashton, where the major problem was potassium deficiency, and found that the manurial effects observed were reflected in the mineral composition of the berries.

Moreover, he (23) has summarized the effects of various orchard factors on the composition of various fruits and has shown that the chemistry of the fruits, both the organic and mineral constituents, are significantly altered by various orchard factors such as varieties, rootstocks, age of plants, cultural practices, manuring, pruning, fruit thinning, bark ringing, time of picking, size grading, etc.

The following are among the more important of his results on fruits which are relevant in the present instance:—

Increased nitrogen supply leads to higher nitrogen content and to lower sugar content in fruits when the nitrogen increase is substantial ; acidity is usually high under low nitrogen conditions.

Potassium deficiency gives slightly variable results but the following are most frequently found: nitrogen content is normal, acidity is low, total sugars may be slightly high or low, reducing sugars are relatively high and sucrose low ; ash content is depressed and the ash shows relatively low K_2O and high CaO and P_2O_5.

Fruits from young plants tend to contain very high nitrogen and sucrose.

Practices etc. which tend to promote favourable conditions for the development of fruits result in relatively high sucrose and low reducing sugars. Late picking leads to increased storage of sucrose.

When a crop is graded for size, sucrose and ash content are automatically graded, the largest fruits containing the highest percentages of sucrose and ash.

The results of the above mentioned workers suggest that many factors may affect the composition of fruits and, although certain appear to be contradictory with respect to specific factors, in other cases the agreement is close and it seems possible that as further data become available certain relationships will become established.

EXPERIMENTAL DATA.

The Plots.

The field experiment was begun in order to investigate the effects of various commercial manurial treatments on strawberry plants. Each treatment is of a type commonly used in commercial strawberry culture, and the experiment was planned to extend over a long period of time and to be continued on the same plot of land throughout.

Table I gives the details of the manurial treatments.

TABLE I.

Manurial Treatments.

Treatment A.	*Dung* at 20 tons per acre to be ploughed in previous to planting. No further manuring to be given during three year period.
Treatment B.	*Dung* at 10 tons per acre to be ploughed in as in A. *In addition* a complete fertilizer to be given each spring as under : Sulphate of Ammonia —to supply 20 lb. N. per acre. Superphosphate —150 lb. Total Phos. per acre. Sulphate of Potash — 50 lb. K_2O per acre.
Treatment C.	*Shoddy* (on basis of 5 per cent total Nitrogen) at rate of 2 tons per acre to be ploughed in as in A. *In addition* to be given each spring as under : Steamed Bone Flour —150 lb. Total Phos. per acre. Sulphate of Potash — 50 lb. K_2O per acre.
Treatment D.	*A "Complete Organic" Manure* (non-bulky) to be applied each spring as under : Dried Blood — 40 lb. N. per acre. Steamed Bone Flour —150 lb. Total Phos. per acre. Sulphate of Potash — 50 lb. K_2O per acre.
Treatment E.	*A "Complete Inorganic" Manure* to be applied each spring as under : Sulphate of Ammonia— 40 lb. N. per acre. Superphosphate —150 lb. Total Phos. per acre. Sulphate of Potash — 50 lb. K_2O per acre.
Treatment F.	*"Organic Manure" containing N. and* P_2O_5 *but no Potash to be given* (*c.v.D.*) *each spring.* Dried Blood — 40 lb. N. per acre. Steamed Bone Flour —150 lb. Total Phos. per acre.
Treatment H.	*Control Plot.* No manure to be given throughout the period of the experiment.

The site of the plots is an open situation which is practically level. It occupies a central position in the plantations at Long Ashton. The drainage of the area is fairly good, although at the beginning of the experiment small patches of the land appeared wet. This condition has since been remedied and the drainage is everywhere satisfactory. The soil of the plots is mainly derived from the underlying Keuper Marl, but the surface soil is rather more sandy than is usual in a typical Keuper Marl soil. This is due to the presence of colluvial material of a more sandy nature. Before 1917 the land had been under grass for many years. When it was broken up it was found to be of rather poor fertility and decidedly acid in reaction. For this latter reason, in 1923 a dressing of ground limestone was given at a rate of two tons per acre.

Mechanical analyses of samples of surface soil and sub-soil from the plots receiving no manurial treatment (H1, H2, H3) were made in 1932. The results of these analyses, together with some chemical data, are given in Table II.

TABLE II.

Soil Analyses. Samples taken February, 1932.

Analyses on Air-dried Samples.

Mechanical Analysis.	Surface.	Subsoil.
	%	%
Stones	<1	Nil.
Coarse Sand	8·45	4·81
Fine Sand	53·93	49·17
Silt	15·65	16·50
Clay	13·60	19·40
Calcium Carbonate	<1	<1
Moisture	1·24	1·09
Loss by Solution	1·58	1·71
Difference	5·55	2·47
Loss by Ignition	2·30	4·97
Chemical Analysis :		
Potash " Available " (K_2O)	0·0126	0·0065
Phosphoric Acid " Available " (P_2O_5) ..	0·0227	0·0092
Calcium Carbonate	<1	<1
Lime requirement	Nil.	Nil.

The plots are arranged in chequer board fashion, and each treatment is given in triplicate. The complete arrangement will be understood by referring to the accompanying diagram. Each plot is approximately 1/60th of an acre, and the amount of manure given in these treatments is calculated on this basis.

The experiment was begun in the spring of 1924 and it was proposed that the plots should be continuously under strawberries for several plantings. Each planting was to remain for three years, but this was not found to be practicable

DIAGRAM I.

Showing Arrangement of Manurial Plots.

North.

	H3	G3	F3	E3	
	A3	B3	C3	D3	
	G2	H2	A2	B2	
West.					East.
	F2	E2	D2	C2	
	H1	G1	F1	E1	
	A1	B1	C1	D1	

South.

in the earlier plantings because of the occurrence of various obscure diseases in the plants, which had therefore to be removed prematurely and the plots replanted.

The variety used throughout has been " Royal Sovereign ", which is the best commercial dessert variety in the district.

The first planting was carried out on April 8th to April 14th, 1924, and various strains from Cheddar which had been received in October, 1923, were used. The delay in planting was due to unfavourable conditions of weather and soil.

The second planting took place between July 13th and August 3rd, 1926, and the plants were strong and of a selected Long Ashton strain.

The third planting, which is considered in the present paper, was carried out on August 6th, 1929, the plants being of a carefully selected strain. They had been raised at the Research Station, were very vigorous and gave uniformly large and fairly fruitful plants. When the samples for analysis were taken, the plots had been under the manurial treatments continuously for seven years, and the plants used were in their second and main year of cropping.

Throughout the experiment the plots have been kept clean cultivated by hoeing when plants have been growing on them, and have been dug only on one or two occasions when wet weather has caused abnormal weed growth. Between each successive planting the plots have been ploughed, and prior to the present series, the whole area was sub-soiled. It may thus be said that throughout the growth history of the present planting, cultural conditions on the plots have been favourable to the growth of excellent plants. The latter have not been allowed to develop runners at any time, but have been grown for fruit only. The berries have been strawed in the usual way to keep them clean.

Manurial Results.

Until the last planting (1929), it has been impossible to obtain accurate quantitative field data of vigour and crop yield because of the incidence of uncontrollable diseases. In spite of this, the following points had become evident during the previous two plantings in 1924 and 1926.

1. The plants on the plots receiving farmyard manure (A. B.) have been more vigorous than any others.
2. The plants on plots where no potassium has been given (F. and the control H.) have not produced plants as vigorous as on the others. The plants have also appeared stunted at fruiting time. In certain seasons the plants on these plots have shown very definite signs of leaf scorch during July.
3. The plants on plots receiving a " complete " fertilizer (C. D. and E.) have appeared intermediate in growth, irrespective of whether the fertilizer has been of organic or inorganic origin. The treatments have not produced such vigorous plants as the farmyard manure, but there has been a very great difference between them and the plants which have received no potassium.

These points have also been evident throughout the present planting, and in order to convey some concrete impression of the relative vigour of the plants under the various treatments, some data extracted from vigour markings made during 1931 are given below. To obtain numerical data, the vigour of the plants by plots was classified as follows:—

Very vigorous plants	4 marks
Fairly ,, ,, ...	3 ,,
Plants medium in vigour	2 ,,
Poor vigour	1 mark

The observations have been made by those who have followed the experiments from the beginning. Independent observations and markings were made by two or more observers, and the resulting data compared before the final figures were decided upon. Since each treatment is in triplicate, the results give a fairly accurate measure of the response of the plants to the various treatments.

During the season 1931 all the plants showed abnormally vigorous growth, due largely to the exceptionally high summer rainfall. The abnormally vigorous growth was apparent particularly in plots E. (" complete " inorganic manure) and C. (" complete " fertilizer containing shoddy, organic phosphorus plus sulphate of potash) and to a less extent in plot D. (" complete " fertilizer containing organic nitrogen and phosphorus plus sulphate of potassium). These three series of plots contained plants which approached in vigour those on plots

A. and B. (farmyard manure) which are usually by far the most vigorous. Even the plants in plots F. and H. (no potassium and no manure) showed greater vigour than usual, although they could easily be distinguished from the rest.

Table III summarizes the results of the vigour markings.

TABLE III.

Markings of Plots for Vigour of Plants—1931.

Treatment.	Description.	May 26.	June 4.	Sept. 9.	Season Totals.
Plots A.	Farmyard manure	11	10½	11½	33
,, B.	Farmyard manure +complete inorganic	11	11	12	33
,, C.	Shoddy + organic phosphate and sulphate of potash	10½	10	10½	31
,, D.	Dried blood and organic phosphate +sulphate of potash	9½	9	10	28½
,, E.	Complete inorganic	10	10	11	31
,, F.	As D., but no sulphate of potash ..	7½	7½	8½	23½
,, H.	No manure	7	7	8½	22½

It will be seen that the final order of vigour over the season was as follows:—

A.	B.	C.	F.	D.	F.	H.
33	33	31	31	28½	23½	23½

The order is significant, and shows the effect of the farmyard manure on the general vigour of the plants in A. and B. Despite the exceptionally heavy and vigorous growth during the season, the differences between the plots which receive a " complete " manure and those which do not receive potash were well marked.

The total weight of fruit harvested from each treatment in 1931 is recorded in Table IV.

TABLE IV.

Strawberry Yields, 1931.

Total Weights of Crops Harvested.

Treatment.	Weight of Fruit in K.g.	Order Total Yields.
Plots A.	253·960	2
,, B.	277·205	1
,, C.	244·360	3
,, D.	223·800	5
,, E.	238·040	4
,, F.	199·125	6
,, H.	181·960	7

When arranged in descending order of total yields the plots fall into the following order:—

High. B., A., C., E., D., F., H. *Low.*

The order of cropping was therefore practically identical with the order of vigour, and it can be stated that there is a good correlation between the vigour of plants and their yield of fruit.

Method of Sampling in the Field.

The picking season in 1931 began on June 20th and continued until July 9th. It was considered desirable to obtain samples for analysis as follows:—

(1) Early fruit.
(2) Early mid-season fruit while size remained large.
(3) Late mid-season fruit when size had fallen off.
(4) Late fruit but still of dessert quality.

The dates of the four picks were accordingly (1) June 26th, (2) June 29th, (3) July 3rd, and (4) July 7th.

In each picking of fruit, 5 lb. of the highest grade of fruit were taken from each treatment, but in the first and second pickings, abnormally large fruits were not included. In order that comparable areas should be sampled on each occasion, an endeavour was made to pick the samples from No. 1 plot in each treatment. This was not possible in the third and fourth pickings, when it was necessary to utilize berries from Nos. 1 and 2 plots in each treatment to obtain suitable bulks of material. All the pickings and selections of the samples for analysis were made by the plot recorder. The harvesting of the samples was carried out simultaneously on each occasion, with the exception of the sample from plot H. in the fourth pick, which was obtained a day before the rest, rain interfering with the picking operations.

Weather.

As previously stated, the rainfall during the season was exceptionally high, and the number of hours of sunshine below the average. During the fortnight before the first sampling there were only two days when rain did not fall. During the early part of the picking period, however, the weather improved but deteriorated again towards the fourth sampling date. Days of little sunshine predominated over the latter period of harvesting and, even when there were fair periods, the sky was frequently overcast.

Laboratory Sampling.

After picking and weighing, each lot of fruit was immediately taken to the laboratory and sampled for analysis. The appearance and number of berries per sample were recorded. The fruit was then hulled and treated as follows:—

Each berry was cut transversely in half. Two thin slices were cut from the centre portion and the remaining pieces put on one side. The thin sections were well mixed in a bowl and from them the portions for the estimation of nitrogen, sugars and acidity were weighed. The material for nitrogen determination (approx. 40 gms.) was transferred directly to a Kjeldahl flask and treated with 40 cc. concentrated sulphuric acid. The portion for sugar analysis (approx. 30 gms.) was washed with alcohol into a wide-necked bottle containing hot alcohol of such a strength that the final concentration of alcohol (when the moisture content of the fruit was taken into consideration) was approximately 85 per cent. This was treated with calcium carbonate to counteract the acidity of the fruit and after bringing to the boil the bottle was corked with a waxed cork and set aside for analysis. The material for the acidity determinations (approx. 50 gms.) was preserved in the same way, but no calcium carbonate was added to the alcohol.

The larger pieces of berry which had been put on one side, were then chopped up finely and well mixed in a large bowl. Approximately 500 gms. were then put into a tared beaker, which was re-weighed to obtain the fresh weight of the material and placed in the oven at 100° C. and dried to charring in readiness for ashing.

The central parts of the fruit were thus reserved for the more delicate estimations which required less material, and the major part of the berry was used for that part of the experiment which required greater bulk of sample.

The fruit was always sampled as quickly as possible after it had reached the laboratory. In no case was any sampling postponed from one day until the next. While waiting to be sampled all fruit was kept in a cool cupboard. The estimations of the constituents were made as soon after the sampling as possible.

CHEMICAL METHODS.

Nitrogen determinations.

The material was digested with 40 cc. concentrated sulphuric acid. The nitrogen was estimated by means of the Kjeldahl-Gunning-Arnold method. ("Methods of Analysis" A.O.A.C. 1930, Chap. II, p. 21.)

Acidity determinations.

The preserved material was extracted in 95 per cent alcohol for twenty-four hours. The alcohol was removed by distillation at 40°-45° C. under reduced pressure. The residue (20-30 cc.) was made up to a known volume, and an aliquot portion neutralized with $\frac{N}{10}$ sodium hydroxide, using phenol phthalein as indicator.

Sugar determinations.

After extraction of the preserved material for twenty-four hours the extract was distilled under pressure at 40°-45° C. The residue was "cleared" by means of the lead acetate-potassium oxalate method, and made up to a known volume. The reducing sugars were estimated directly by Lane and Eynon's method. (J. Soc. Chem. Ind. Vol. 42, p. 32, 1923, Vol. 44, p. 150, 1925.) An aliquot portion of the cleared solution was hydrolyzed with 10 per cent citric acid and after neutralizing, the total sugars were estimated as before. Sucrose contents were obtained by calculation from these two sets of results.

Ash Content.

The dried material was ashed at a low temperature in a gold dish. The ash was leached, the residue ignited at a higher temperature, and cooled. The leachings were then added and evaporated. The resulting ash was weighed and recorded as percentage ash in fresh weight.

Ash Constituents.

Calcium was precipitated as calcium oxalate and subsequently titrated with $\frac{N}{10}$ potassium permanganate; magnesium estimated gravimetrically as pryophosphate; potassium by the perchlorate method; sodium as the triple salt, sodium-zinc-*uranyl* acetate, after the method of Barber and Kolthoff (J. Amer. Chem. Soc. Vol. 50, 1928); phosphates by the volumetric ammonium molybdate method: iron and manganese were estimated colorimetrically; silicia was obtained by treatment of the ash with hydrochloric acid, and weighing the insoluble portion.

RESULTS.

Berry Size.

Data relating to berry size were obtained by counting the berries in each 5 lb. sample as it came into the laboratory and are summarized in Table V.

TABLE V.

Number of Berries in each 5 lb. Sample.

Treatment.	Pick No. 1.	Pick No. 2.	Pick No. 3.	Pick No. 4.	Total No. of Berries from each Treatment for four Picks.
Plots					
A. ..	129	103	184	194	610
B. ..	138	107	169	182	596
C. ..	141	140	157	200	638
D. ..	119	154	196	200	669
E. ..	136	114	166	177	593
F. ..	146	118	192	195	651
H. ..	152	112	209	212	685
Total No. of Berries in each Pick ..	961	848	1273	1360	

They show clearly any differences in berry size between the samples from the different treatments, and also the changes in size at each pick. In reading the table, it should be borne in mind that berry size is inversely proportional to the number of fruits in the sample.

Nitrogen Content.

The results of the estimations of the total nitrogen are given in Table VI, the values being expressed as percentages of the fresh weights. In each case the determinations were made in duplicate, but since the values obtained were very close, the mean results only are given.

TABLE VI.

Total Nitrogen Expressed as Percentage Fresh Weight.

Treatment.	Pick No. 1.	Pick No. 2.	Pick No. 3.	Pick No. 4.	Mean Nitrogen for each Treatment.
Plots					
A. ..	0·108	0·100	0·097	0·096	0·100
B. ..	0·117	0·124	0·101	0·088	0·108
C. ..	0·108	0·099	0·096	0·084	0·097
D. ..	0·108	0·116	0·093	0·090	0·102
E. ..	0·116	0·112	0·100	0·093	0·105
F. ..	0·116	0·109	0·104	0·094	0·106
H. ..	0·117	0·099	0·094	0·088	0·099
Mean for each Pick ..	0·113	0·109	0·098	0·090	

Total Acids.

As in the case of the nitrogen figures, the mean results of the duplicate estimations of the acidity are given in Table VII. The acidity is calculated as malic acid and is given as percentage of the fresh weight.

TABLE VII.

Percentage Acid in Fresh Weight. Calculated as Malic Acid.

Treatment.	Pick No. 1.	Pick No. 2.	Pick No. 3.	Pick No. 4.	Mean Acidity for each Treatment.
Plots					
A. ..	0·921	0·803	0·828	0·751	0·826
B. ..	0·932	0·762	0·795	0·747	0·809
C. ..	0·935	0·814	0·845	0·804	0·849
D. ..	0·939	0·831	0·838	0·784	0·848
E. ..	0·944	0·825	0·841	0·609	0·805
F. ..	0·899	0·703	0·777	0·680	0·765
H. ..	0·900	0·721	0·814	0·799	0·808
Mean Acidity for each Pick	0·939	0·780	0·820	0·753	

Total Sugars.

These are shown in Table VIII. They are calculated from duplicate results and are expressed as percentages of invert sugar in fresh weight.

TABLE VIII.

Total Sugars (expressed as Invert Sugar) in Percentage Fresh Weight.

Treatment.	Pick No. 1.	Pick No. 2.	Pick No. 3.	Pick No. 4.	Mean Total Sugars for each Treatment.
Plots					
A. ..	5·29	5·85	4·96	5·37	5·37
B. ..	4·63	5·19	5·45	5·75	5·25
C. ..	5·18	4·99	5·44	6·03	5·41
D. ..	4·68	4·88	5·19	5·98	5·18
E. ..	4·87	5·11	5·36	5·65	5·25
F. ..	5·01	5·10	5·00	5·87	5·25
H. ..	5·08	5·32	5·66	6·09	5·53
Mean Total Sugar for each Pick ..	4·96	5·21	5·29	5·82	

Reducing Sugars.

These are given in Table IX as percentage of lævulose in fresh weight. The figures are the result of duplicate estimations.

TABLE IX.

Reducing Sugars as Percentage Lævulose in Fresh Weight.

Treatment.	Pick No. 1.	Pick No. 2.	Pick No. 3.	Pick No. 4.	Mean Percentage Reducing Sugars for each Treatment.
Plots					
A. ..	3·99	3·85	3·64	3·75	3·81
B. ..	3·87	3·74	3·50	3·96	3·77
C. ..	4·02	3·56	3·69	4·13	3·85
D. ..	3·69	3·65	3·62	4·17	3·78
E. ..	3·92	3·92	3·91	3·96	3·93
F. ..	3·76	3·73	3·81	3·99	3·82
H. ..	3·90	4·02	4·02	4·30	4·06
Mean Reducing Sugars per Pick ..	3·88	3·78	3·76	4·04	

Sucrose.

Sucrose has been calculated from the figures obtained for total and reducing sugars. The values are therefore also from duplicate estimations and are calculated as percentages of the fresh weights—Table X.

TABLE X.

Sucrose as Percentage Fresh Weight.

Treatment.	Pick No. 1.	Pick No. 2.	Pick No. 3.	Pick No. 4.	Mean Sucrose for each Treatment.
Plots					
A. ..	1·38	1·88	1·30	1·62	1·55
B. ..	1·06	1·48	1·87	1·90	1·58
C. ..	1·21	1·46	1·78	1·89	1·59
D. ..	1·06	1·21	1·57	1·89	1·43
E. ..	1·19	1·23	1·46	1·68	1·39
F. ..	1·17	1·41	1·27	1·37	1·31
H. ..	1·20	1·34	1·62	1·85	1·50
Mean Sucrose for each Pick	1·18	1·43	1·55	1·74	

Ash Constituents.

Tables XI—XIV present the results of the ash analysis of the fruits for the four picks. The first column in each table gives the results for the carbonate ash as percentage of the fresh weight. In the remaining columns the various ash constituents are expressed as percentages of the carbonate ash.

TABLE XI.

Total Ash and Ash Constituents—1st Pick.

Plot.	Ash (as % Fresh Weight).	Ash Constituents, calculated as % Ash.								
		SiO_2	Fe_2O_3	Al_2O_3	Mn_3O_4	CaO	MgO	K_2O	Na_2O	P_2O_5
A.	0·356	2·79	0·17	0·315	0·061	6·33	4·55	51·28	0·61	13·24
B.	0·374	2·01	0·31	0·323	0·065	6·36	4·76	50·47	0·56	14·16
C.	0·368	3·14	0·75	0·057	0·075	5·76	4·77	49·96	0·57	12·76
D.	0·378	2·47	0·17	0·260	0·085	6·41	4·48	50·12	0·56	11·54
E.	0·388	2·15	0·72	0·054	0·129	5·25	4·76	50·95	0·66	13·10
F.	0·352	3·43	0·74	0·061	0·106	6·85	4·78	45·0	1·38	13·95
H.	0·346	2·41	0·54	0·270	0·071	7·71	4·83	47·63	0·54	13·87

TABLE XII.

Total Ash and Ash Constituents—2nd Pick.

Plot.	Ash (as % Fresh Weight).	Ash Constituents, calculated as % Ash.								
		SiO_2	Fe_2O_3	Al_2O_3	Mn_3O_4	CaO	MgO	K_2O	Na_2O	P_2O_5
A.	0·340	2·37	0·24	0·302	0·068	5·89	4·83	49·60	0·34	13·57
B.	0·389	3·00	0·56	0·302	0·085	5·75	4·25	48·54	0·47	13·35
C.	0·376	2·18	0·56	0·191	0·113	5·97	4·49	47·79	0·36	12·56
D.	0·359	1·36	0·32	0·203	0·108	6·74	4·49	50·16	0·72	14·19
E.	0·378	1·89	0·57	0·137	0·165	5·16	4·63	51·93	0·28	12·65
F.	0·327	1·96	0·46	0·151	0·116	6·55	4·70	48·51	0·41	13·98
H.	0·329	2·57	0·26	0·191	0·03	7·14	4·72	47·88	0·55	13·97

Table XIII.

Total Ash and Ash Constituents—3rd Pick.

Plot.	Ash (as % Fresh Weight).	Ash Constituents, calculated as % Ash.								
		SiO_2	Fe_2O_3	Al_2O_3	Mn_3O_4	CaO	MgO	K_2O	Na_2O	P_2O_5
A.	0·376	2·78	0·30	0·238	0·045	7·04	4·81	48·86	0·37	12·77
B.	0·370	1·53	0·22	0·167	0·084	6·31	4·60	50·13	0·27	13·99
C.	0·369	1·58	0·18	0·177	0·071	7·48	5·02	48·55	0·42	12·05
D.	0·369	2·80	0·27	0·173	0·086	6·75	4·85	46·61	0·30	12·25
E.	0·377	1·44	0·45	0·188	0·121	5·96	4·73	50·10	0·25	12·96
F.	0·315	2·57	0·31	0·132	0·067	8·12	4·77	46·29	0·51	13·94
H.	0·341	2·48	0·40	0·095	0·089	9·58	5·12	46·13	0·59	13·93

Table XIV.

Total Ash and Ash Constituents—4th Pick.

Plot.	Ash (as % Fresh Weight).	Ash Constituents, calculated as % Ash.								
		SiO_2	Fe_2O_3	Al_2O_3	Mn_3O_4	CaO	MgO	K_2O	Na_2O	P_2O_5
A.	0·367	2·76	0·30	0·209	0·088	7·83	4·39	47·57	0·48	14·16
B.	0·373	1·93	0·29	0·119	0·043	7·11	4·61	46·36	0·30	13·25
C.	0·347	2·96	0·32	0·145	0·079	8·76	5·05	46·35	0·38	12·56
D.	0·342	2·89	0·67	0·175	0·133	8·66	4·94	45·64	0·44	13·36
E.	0·356	1·74	0·30	0·186	0·040	7·45	4·45	50·78	0·53	13·56
F.	0·324	2·99	0·50	0·214	0·113	10·01	4·67	43·78	0·54	15·23
H.	0·341	2·08	0·26	0·136	0·087	9·99	5·24	45·08	0·54	13·95

In Tables XV—XVIII the more important constituents of the ash are tabulated as percentages of the fresh weights. The mean values for each constituent have been calculated and are shown at the bottom of their respective columns.

Table XV.

Ash Constituents as Percentage Fresh Weight—1st Pick.

Plot.	CaO	MgO	K_2O	Na_2O	P_2O_5
A.	·02250	·01671	·1845	·002003	·04708
B.	·02375	·01827	·1884	·002368	·05342
C.	·02188	·01752	·1854	·002290	·04741
D.	·02430	·01701	·1875	·002305	·04369
E.	·02129	·01840	·1977	·002270	·05094
F.	·02507	·01606	·1644	·004754	·04913
H.	·02665	·01594	·1602	·001859	·04794
Means for each Constituent ..	0·02363	0·01713	0·1812	0·002550	0·04852

TABLE XVI.

Ash Constituents as Percentage Fresh Weight—2nd Pick.

Plot.	CaO	MgO	K_2O	Na_2O	P_2O_5
A.	·02126	·01740	·1787	·001216	·04895
B.	·02192	·02192	·1921	·001847	·05187
C.	·02244	·02244	·1797	·001360	·04723
D.	·02416	·02416	·1800	·002587	·05091
E.	·01951	·01951	·1964	·001039	·04785
F.	·02143	·02143	·1588	·001342	·04575
H.	·02349	·02349	·1575	·001488	·04599
Means for each Constituent	0·02203	0·02148	0·1776	0·001554	0·04836

TABLE XVII.

Ash Constituents as Percentage Fresh Weight—3rd Pick.

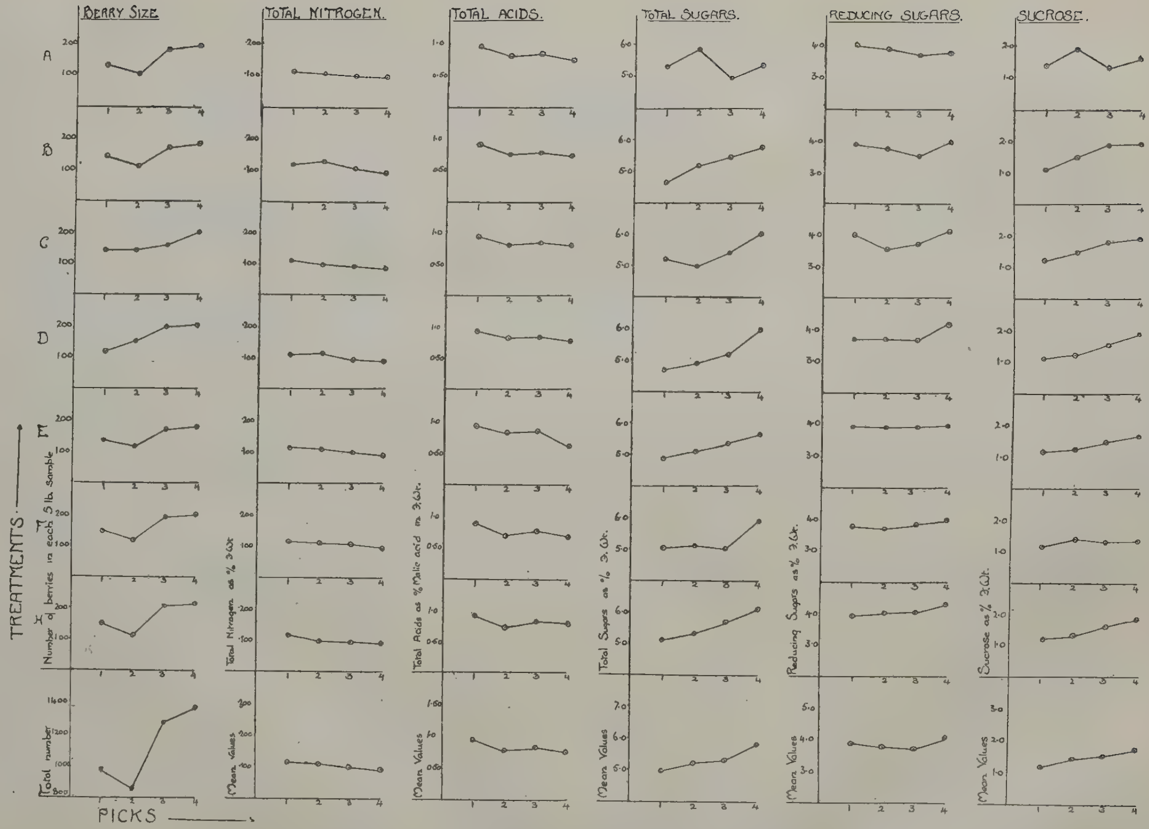
Plot.	CaO	MgO	K_2O	Na_2O	P_2O_5
A.	·02643	·01807	·1723	·001373	·04785
B.	·02330	·01663	·1855	·000985	·05171
C.	·02762	·01852	·1792	·001538	·04447
D.	·02489	·01780	·1710	·001091	·04493
E.	·02245	·01782	·1887	·000940	·04881
F.	·02557	·01501	·1457	·001614	·04388
H.	·03265	·01774	·1571	·002011	·04746
Means for each Constituent	0·02613	0·01737	0·1714	0·001365	0·04702

TABLE XVIII.

Ash Constituents as Percentage Fresh Weight—4th Pick.

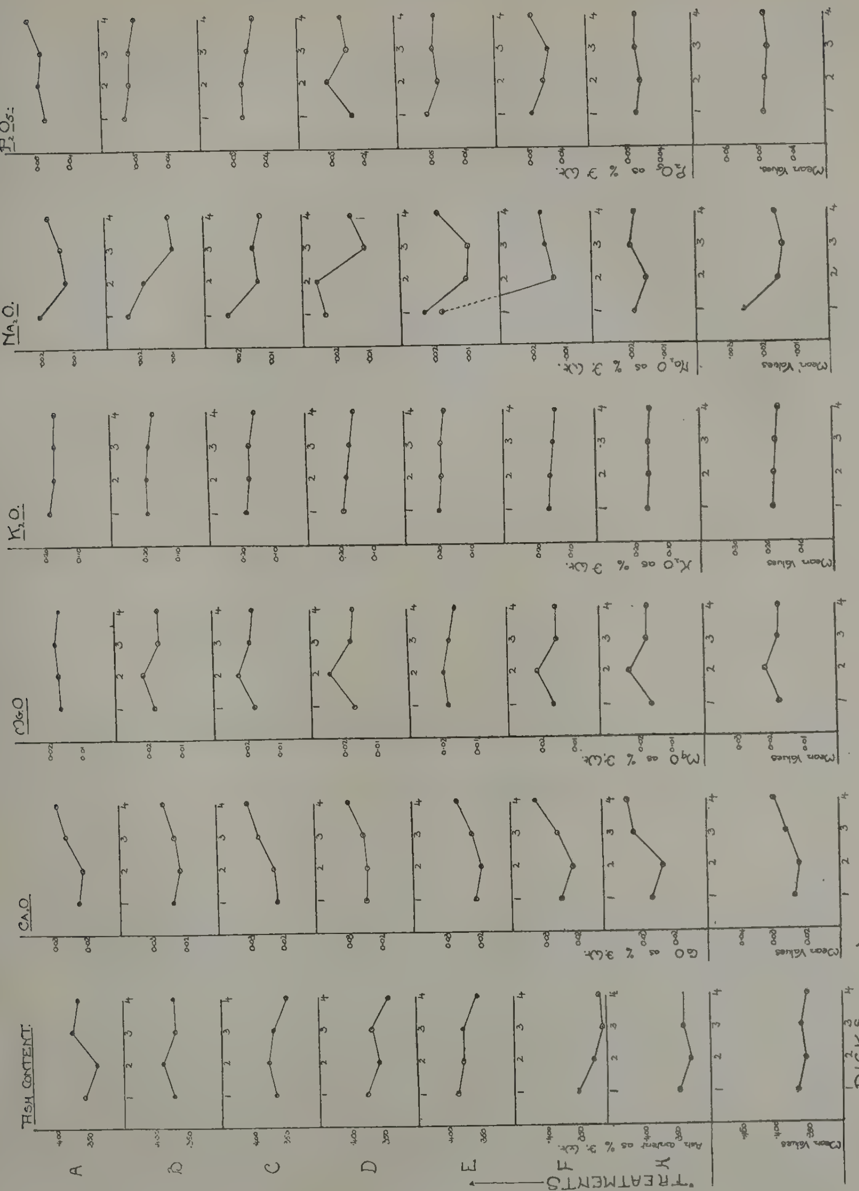
Plot.	CaO	MgO	K_2O	Na_2O	P_2O_5
A.	·02875	·01648	·1746	·001759	·05199
B.	·02650	·01720	·1730	·001129	·04944
C.	·03039	·01750	·1608	·001334	·04356
D.	·02960	·01690	·1562	·001510	·04740
E.	·02649	·01581	·1805	·001891	·04819
F.	·03253	·01517	·1422	·001743	·04946
H.	·03406	·01783	·1536	·001851	·04752
Means for each Constituent	0·02976	0·01670	0·1630	0·001602	0·04822

In order to facilitate the discussion of the results detailed in Tables V—XVIII the various features requiring mention have been expressed graphically in Graphs I and II.



GRAPH I. ANALYSES OF STRAWBERRY FRUITS.

Showing the seasonal effect on berry size and on total nitrogen, total acids, total sugars, reducing sugars and sucrose. The mean seasonal effects are shown at the base of each set of graphs.



GRAPH II. ANALYSES OF STRAWBERRY FRUITS.

Showing the seasonal effect on ash content and on the chief chemical constituents of the ash. The mean seasonal effect is shown at the base of each set of graphs.

DISCUSSION OF RESULTS.

Since the changes in the composition of the fruits over the picking season are being investigated as well as the effects of manurial treatments, the results are discussed from two points of view:—

(a) the variation in composition over the picking season ;

(b) the variation in composition due to the differential manurial treatment.

The field data cannot be discussed in this manner. It has already been shown that there is a good correlation between the vigour of the plants and the yields of fruit. Wentworth (26) has shown that this is not always so, for in cases where excessive vegetative vigour results from applications of nitrate fertilizers, the plants may not produce fruit in proportion to their vigour and yields may even be depressed. In the present instance, however, there are no cases in which nitrogen has been applied in excessive quantities, whilst it also appears that potassium is a limiting factor in the area and increases in crop and vigour are associated with added supplies of this element.

Fruit Size. (Table V, Graph I.)

The results show that the berry size can be classified by picks into two groups, viz. large and small.

	First Pick.	Second Pick.	Third Pick.	Fourth Pick.
Total No. Berries in each picking.	961	848	1273	1360
	Large size.		Small size.	

There is no smooth gradation of size in the picks considered throughout the season, but there is a definite break dividing the berries into these two categories.

When considering the total number of berries for the four picks from each treatment, the following order emerges:—

	E.	B.	A.	C.	F.	D.	H.	
Large.	593	596	610	638	651	669	685	Small.

This order does not correlate completely with the results obtained from the vigour marking, or with the yield of fruit, but it can be seen that those treatments which give low vigour and yield (i.e. F. and H.) definitely produced small sized berries. The "complete" inorganic manure (E.) and the combination of farmyard manure and inorganic fertilizer (B.) are the treatments which produced the largest fruits. Farmyard manure alone also gave rise to fruits of good size. The fertilizers supplying organic nitrogen and phosphorus (C., F. and D.) definitely produced fruits of a smaller size. No reason can be advanced for the position of D. in the scale below F., for the plots received identical amounts and forms of nitrogen and phosphorus, but D. also has potash supplied whereas F. has no supply of this element.

Total Nitrogen. (Table VI, Graph I.)

The seasonal effect on the nitrogen content of the fruits is clearly seen in the graph. There is a very even and distinct fall in percentage nitrogen over the season. The result is similar to those of Gustafson (10) for the content of nitrogen in the tomato over the growing season to the ripening stage, and to those of Nightingale, Addoms and Blake (16) for the peach during ripening. It should be noted in the present case that the comparison is between fruits which ripen at different stages of the picking season and is not necessarily between fruits at differing stages of ripeness. The result suggests that during the harvesting season, the supply of nitrogen available to the fruits becomes gradually lessened, which is in accordance with the findings of Murneek (14, 15) in studies on the tomato, who showed that the fruiting process involved heavy drains on the nitrogen reserves of the plants.

The order of nitrogen content over the season by plots is as follows:—

High. B. F. E. D. A. H. C. *Low.*

There is a wide difference in the nitrogen contents of berries from treatment B. (farmyard manure + inorganic fertilizer) and of those from treatment A. (which has only farmyard manure) although the amounts of nitrogen given in the two cases are approximately equal. It would, therefore, appear that the nitrogen from the dung was not so easily available during the season as that from the inorganic material. The high position of E. also supports this view. The positions of fruits having treatments F. and H. are striking, for whereas the plants and crops are similar in field characters, yet the fruits from plot F. have a definitely high nitrogen, while those from H. have a very low nitrogen content. The results thus serve to differentiate between the fruits from the two treatments although differences cannot be observed in the field data. They also show that the poor performance of the plants on F. is definitely not due to inability to absorb nitrogen.

The fruits from plots B. and E., which receive nitrogen in an inorganic form, show high proportions of nitrogen, whilst fruits from plot C., where the source of nitrogen is shoddy, have the lowest nitrogen content. It seems probable that the nitrogen in shoddy was not so easily available to the plants as that from the inorganic fertilizers. There is no positive correlation between vigour and nitrogen content in the fruit from plots A., F. and C., but fruits from plots B. and E. which receive inorganic nitrogen and have a high nitrogen content are vigorous.

Total Acids. (Table VII, Graph I.)

The seasonal effect on the acidity of the fruit can be seen on Graph I. It is very irregular, but the acid tends on the whole to decrease. Nightingale, Addoms and Blake (16) also showed irregularities during the ripening of peaches, with an upward trend until near the final ripening point, when there was a sharp decrease. Whereas it might have been expected from tasting experience that the acidity of the fruit would decrease substantially during the season, it appears that the acid flavour in the fruits is determined rather by the sugar/acid ratio than by the acid content alone.

The order of acidity of fruits from the plots receiving differential treatments is as follows:—

High. C. D. A. B.H. E. F. *Low.*

The fruits from the plots which are low in potassium have also a low acid content (F. H.). It should be noticed in this connection that H. is also a low nitrogen plot which would tend to raise the acidity. The potash effect is in accordance with the results of Wallace (23) and Vogel and Weber (21). Acidity and nitrogen appear to be negatively correlated. Plot H. again is an exception due to the complication of low potassium. This negative correlation is not in agreement with the results of Greve and Shoemaker (9), who found that nitrogenous dressings to strawberries increased both nitrogen content and acidity. Nightingale, Addoms and Blake (16), in comparing the acidities of peaches over the ripening period from " high " and " low " nitrogen trees, found large differences in nitrogen contents of the fruits at all times but the differences in acidities were rather indefinite, though high nitrogen content tended to be associated with low acidity values.

Total Sugars. (Table VIII, Graph I.)

The seasonal effect on the total sugars is shown to be in a definite upward direction, which is similar to a ripening effect (16) and in accordance with the results of Kimbrough (11).

The order of total sugars throughout the season according to treatment is as under:—

High. H. C. A. / B. E. F. D. *Low.*

The plots may be divided into two definite groups, i.e. plots producing fruits of high sugar content (H. C. A.) and others producing fruits of low sugar content (B. E. F. D.). In plot A., the total sugar content of the fruits is very high in the second picking. The fruits from plot F. also show some irregularity in total sugar content over the season, but it is not so marked as in those from the plot receiving farmyard manure.

When considering the order of total sugar content, it will be seen that there appears a close *negative* correlation with the nitrogen content. Plot D., only, proves an exception to this statement. This negative correlation is in accordance with the results of Gourley and Hopkins (8), Nightingale, etc. (16), Greve and Shoemaker (9), Wallace (23) and others. The anomalous position of the fruits from plot D. is not explicable at the moment but, in any case, is not of major importance.

The fruits from plot H. have an entirely different order of total sugar content from those of plot F. Since both plots suffer visibly from potassium deficiency it might have been expected that the fruits from the two plots would be alike in their total sugar content. The difference is doubtless associated with the different nitrogen status of the two plots.

Reducing Sugars. (Table IX, Graph I.)

The seasonal effect on the reducing sugars is not regular or consistent. In the fruits from plot E. the values remain practically constant throughout the season, and in the other cases they fluctuate in an irregular fashion.

The season's results of the reducing sugar estimations show the following order in the treatments:—

High. H. E. C. F. A. D. B. *Low.*

It will be seen that the fruits from plot H. take first place, and that the values for reducing sugars in these are considerably higher than the fruits from the remaining treatments.

This result is in agreement with a large body of data accumulated at Long Ashton, relative to the composition of fruits grown under unfavourable nutrient conditions (23). Such conditions frequently result in high total sugars and invariably in comparatively high proportions of reducing sugars to sucrose. In this case both potassium and nitrogen are limiting factors.

A similar condition of a relatively high ratio of reducing sugar to sucrose is evident in the fruits from plot F. where potassium deficiency occurs.

Sucrose. (Table X, Graph I.)

There is a very distinct upward trend in the sucrose content of the strawberries from every plot during the season, though the values for treatments A. and F. show irregularities. The curves of the graphs plotted for total sugar and sucrose content are very similar. This is especially clear in the graphs plotted of the results from the fruit of plot A., for in this case the irregularity which is so striking in the total sugar content, is also found in the sucrose content.

In the apple, the percentage sucrose has been positively correlated with the size of the fruit when a single crop is graded by size, i.e. in smaller fruits the sucrose is less (23). This correlation is not found in these results for strawberries picked at different dates, for whereas the size of the fruits was found to decrease through the season, the percentage sucrose had increased. It thus appears that the seasonal effect which produces an increase in sucrose content has outweighed any change which might be due to decrease in size. If each picking had been graded and the sucrose estimated in each grade, it might have been possible to show a similar result for the crop from each pick to that which has been obtained with other fruits.

In classifying the strawberries from each treatment according to their sucrose contents over the four picks, the following order is obtained:—

High. C.B. A. H. / D. E. F. *Low.*

The plots can be grouped in a somewhat similar way to that which was possible in the case of the total sugar estimations. The only plot which has markedly altered its position in the list is plot H., in which the treatment is such that the major part of the sugar content remains as reducing sugars, and the percentage of sucrose—and the position of plot H. in the list—is correspondingly lowered. The fact that fruit from plot F. has the lowest sucrose content, is in accordance with frequent findings of Wallace (23), in which potassium deficiency in the plant has been associated with low sucrose content in the fruit.

Ash and Ash Constituents. (Table XI, Graph II.)

The seasonal effect on the percentage of ash in the fresh weight of the fruits is not significant. It can be represented by the mean percentage ash for each picking.

	First Pick.	Second Pick.	Third Pick.	Fourth Pick.
Mean % ash in fresh weight	0·366	0·357	0·360	0·350

These figures show that there is a slight fluctuation in the ash content, but the difference from pick to pick is not regular. Gustafson (10) found little change in the ash content of tomatoes over the growth period to the ripening stage, with the exception of an initial fall and then a tendency to increase.

When the plots are listed in the order of the mean percentage ash of the strawberries grown upon them, the following order is obtained:—

	B.	E.	C.	D.	A.	H.	F.
Mean % ash in fresh weight . .	0·377	0·375	0·365	0·362	0·360	0·339	0·330

There appears a definite correlation between the ash contents of the fruits and the manurial treatments they have received. The omission of potash (H. F.) has had an especially marked effect, the ash contents of the fruits from these plots being well below those of any other treatments. This result is in complete agreement with the results obtained by Wallace [(24) and unpublished data] when working with gooseberries, apples, plums, and other fruits. Since the ash of normal strawberry fruits contains approximately 50 per cent K_2O, it would be expected that deficiency of potassium would affect the total ash content. The plots receiving "complete" inorganic fertilizers (B. and E.) produce fruits with the highest ash contents. Farmyard manure (A.) alone, has produced a relatively low ash content. It will be seen that there is no simple correlation between the ash content and the nitrogen, acidity or sugar content of the fruits.

The Ash Constituents as Percentage Fresh Weight. (Tables XV—XVIII, Graph II.)

Since potassium deficiency has been shown in the previous discussion to be an important factor, the percentages of potassium in the fresh weight of fruit from the different treatments is considered first in discussing features relating to the ash constituents.

The average percentages of K_2O in the four pickings are as follows:—

	First Pick.	Second Pick.	Third Pick.	Fourth Pick.
Mean % K_2O in fresh weight	0·1812	0·1776	0·1714	0·1630

These figures show that there is a gradual decrease in the potassium content of the berries throughout the season. Gustafson (10) found the percentage of potassium in the fruits of tomatoes to remain practically constant to the ripening stage, only a very slight fall being apparent. It would seem possible that the decrease is due to a gradual exhaustion of supply either because of a decrease in external supply or because of the inability of the conductive tissues of the plant to cope with the drain on reserves set up by the rapidly developing succession of fruits.

The percentage of K_2O in the fresh weight of the fruits from each treatment decreases as shown in the following list:—

	E.	B.	A.	C.	D.	H.	F.
Mean K_2O in four picks ..	0·1908	0·1850	0·1775	0·1763	0·1737	0·1571	0·1528

The order shows good agreement between the potassium content and the ash content of the berries. The fruit from plot A. proves an exception, being in the low group for total ash, but in the high group for potassium content. The case provides an example of farmyard manure supplying adequate potash on a potash deficient area. It is notable that the fruits from the plots receiving inorganic artificial fertilizers have the highest potassium contents. The order for potassium content is also similar to that for berry size.

The plots which have received no potassium in their manurial treatments (F. H.) have produced fruits whose potassium contents are very low. This supports Wallace's finding (24) that " where the plants do not receive any potash manures . . . the deficiency of potassium is reflected in the composition of portions of plants which have been subjected to analysis ". It will thus be seen that the potash values reflect the manurial treatments in a very clear way.

Calcium : The seasonal changes in the calcium content of the berries are demonstrated by the figures for the mean percentage of calcium in each picking.

	First Pick.	Second Pick.	Third Pick.	Fourth Pick.
Mean % of Calcium (CaO in fresh weight) ..	0·02363	0·02203	0·02613	0·02976

The calcium content of the berries in the two earlier pickings segregate sharply from those of the two latter ones, being much higher in the later picks. It should be noted that the data for berry size showed a similar segregation of values and the possibility of a negative correlation between berry size and calcium content would appear to require further examination. A negative correlation is also indicated between size and calcium contents of the berries according to treatment. (See order immediately below.)

The order of the plots according to the mean percentages of calcium in the respective fruits is as follows:—

	H.	F.	D.	C.	A.	B.	E.
Mean % of CaO in the four picks ..	0·02921	0·02615	0·02574	0·02558	0·02474	0·02387	0·02244

The most striking aspect of these results is the very close negative correlation which appears between the calcium content and the potassium content of the berries. This correlation has also been found by Wallace (22) when working on gooseberry manurial trials and potassium deficiency investigations, and by Davis (5) in nutritional studies on apple trees. There is a distinct segregation of those plots which are deficient in potassium (H. F.), and the plots which receive farmyard manure and " complete " inorganic fertilizer are lowest.

Magnesium : The seasonal effect on the magnesium content, as tabulated below, shows that the content of this element varies irregularly from picking to picking and shows no consistent trend.

	First Pick.	Second Pick.	Third Pick.	Fourth Pick.
Mean % MgO in fresh weight	0·01713	0·02148	0·01737	0·01670

Gustafson (10) obtained similar results in his investigations on the tomato. He found that, whereas in one variety there was an increase throughout the season, in another the values for the magnesium content had no definite variation in either direction.

The tabulation by plots over the season is as follows:—

	C.	D.	H.	B.	E.	A.	F.
Mean % MgO of four picks ..	0·01900	0·01897	0·01875	0·01851	0·01789	0·01717	0·01692

These results cannot be correlated with any others previously discussed, and in particular they show no relationship to the values obtained for calcium, potassium or phosphorus.

Sodium : The seasonal effect on the sodium content of the fruits is expressed as follows:—

	First Pick.	Second Pick.	Third Pick.	Fourth Pick.
Mean % Na_2O in fresh weight	0·00255	0·00155	0·00137	0·00161

The graphs show that the occurrence of sodium is very irregular. The first pick seems to have a much higher average sodium content than the succeeding picks. This is accounted for by the high percentage of sodium in the first pick from plot F. The result was obtained on duplicate samples of berries and thus appears to be truly representative of the pick for that plot.

The order of sodium content according to plots is as follows:—

	F.	H.	D.	C.	A.	B.	E.
Mean % Na_2O in fresh weight ..	0·00236	0·00187	0·00180	0·00163	0·00159	0·00158	0·00153

The order indicates a positive correlation with the calcium content and a negative one with the potassium content of the fruits.

Phosphorus: There is no significant change during the season in the percentage of phosphorus found in the fruits examined. The results from pick to pick are irregular and are as follows:

	First Pick.	Second Pick.	Third Pick.	Fourth Pick.
Mean % P_2O_5 in fresh weight	0·04852	0·04836	0·04702	0·04822

The irregularities shown are probably not significant and it may be said that the percentage of phosphorus remains nearly constant throughout the season. This is also in agreement with the results of Gustafson (10) for the tomato.

The order of the plots over the season is as follows:—

B.	A.	E.	H.	F.	D.	C.
0·05161	0·04897	0·04895	0·04723	0·04706	0·04673	0·04567

There is no correlation of these results with any others that have been recorded previously. The association of potassium deficiency and increased phosphorus content which has been previously noticed by Wallace (22) and Owen (17) does not appear clearly in this instance, though it should be noted that the plots which receive organic phosphorus and potassium (C. D.) have produced fruits with lower phosphorus contents than those from the potassium deficient plots (F. H.), F. receiving equivalent organic phosphorus to C. and D., and H. no phosphorus.

The Ash Constituents as Percentage of the Ash. (Table XI.)

Potassium (as K_2O) constitutes approximately 50 per cent of the ash of the strawberry. Phosphorus (as P_2O_5) ranges from 12—14 per cent of the ash, and calcium (as CaO) varies from 5·0—7·0 per cent. Magnesium and sodium (as MgO and Na_2O respectively) are approximately 4·5 per cent and 0·4 per cent. The other constituents, e.g. manganese, silicon, iron, though important in nutrition, are present in very small quantities and show no definite trend in one direction or another.

In discussing the results for potassium and calcium in fresh weight, it was pointed out that a good negative correlation appeared between the two elements. This is further evidenced in the percentages of K_2O and CaO in the ash, where the former falls as the season advances and the latter shows corresponding increases. No definite seasonal trends or relationships can be seen in the cases of the other constituents.

It must be remembered that these results are obtained from the ash of the complete fruits, i.e. the ash of pulp and seeds. They are therefore analogous to the values obtained for the analyses of gooseberries which are also composed of both pulp and seeds. Results for apple pulp show that the percentage of potassium (as K_2O) in the ash may be as high as 55 per cent (23) where the supply of the element is adequate. The results obtained for strawberries (in which there is a large proportion of pulp and a comparatively small proportion of seed matter) have an intermediate position, as far as the potassium content is concerned, between the results obtained for gooseberries and those wholly from pulp (i.e. apple).

CONCLUSIONS.

From the foregoing discussion the following conclusions seem justified:—

(1) A close correlation was found between the vigour of the plants and the yield of fruits from them. The plants which received farmyard manure are the most vigorous and have produced the largest crops, and those growing under conditions of potassium deficiency have proved the lightest croppers.

(2) The largest fruits were obtained from plots receiving a complete inorganic fertilizer and farmyard manure, while the smallest fruits were obtained from those plots which received no potassium treatment.

(3) There is a fall in the percentage of nitrogen in the fruits over the picking season. This is very even and distinct. Inorganic manures were associated with fruits of high nitrogen content, whereas farmyard manure alone and manures of organic origin (i.e. nitrogen and phosphorus given in organic form) produced fruits with relatively low contents of nitrogen. Potassium deficient fruits contained a high percentage of nitrogen where nitrogen was given in the manurial treatment. The treatments " no manure " and " omitting potash " can be differentiated by the nitrogen contents of the berries.

(4) The acidity of the strawberries in this investigation varies in an irregular way throughout the season but tends to decrease. Acidity and nitrogen content showed a negative correlation by treatments except in one case, where both low nitrogen and low potassium are factors. In this instance potassium deficiency is the complicating factor since this brings about low acidity.

(5) The total sugar content of the fruits increased as the season progressed. There appeared a negative correlation between total sugar content and nitrogen content.

(6) The reducing sugars are highest in those fruits receiving no manurial treatment. This is probably due to the failure of the fruits to synthesize sucrose under the conditions of limited food supply.

(7) The sucrose content increased throughout the season and was not closely correlated with berry size, the fruits from plots E. and H. (high and low nitrogen respectively) being widely out of place. It was generally correlated with total sugars, but deficiency effects appeared to upset the relationship. The potassium deficient fruits were low in sucrose. The plants on plots receiving shoddy and farmyard manure produced fruits which had high sucrose contents.

(8) Ash content seemed correlated with manurial treatments, inorganic fertilizers producing a high ash content, organic materials less, and potassium deficiency being associated with the lowest amounts of ash.

(9) The potassium content of the fruits decreased over the picking season, and was lowest in those fruits from plots where no potassium is given. Potassic manures significantly increased the percentage of potassium in the berry. The potassium content of the fruits showed a positive correlation with total ash and was negatively correlated with calcium. Farmyard manure was an efficient source of potassium on the plots.

The calcium content may be negatively correlated with berry size and is in negative correlation with the potassium content.

The magnesium content of the fruit showed little variation throughout the season, and had no apparent relation to any other results.

The phosphorus content also remained approximately constant throughout the season and was highest in the fruits from plots receiving farmyard manure.

There was no seasonal change discernible in the percentage sodium content of the fruits in this experiment, but there appeared to be a negative correlation of sodium and potassium contents by plots.

SUMMARY.

(1) An investigation into the effect of different manurial treatments on the chemical composition of strawberry fruits over the picking season of 1931 is described. During the work, attention was also given to the effects of the treatments on vigour and yield of the plants and on the size of the fruits.

(2) The manurial treatments considered had been given to the plots over a period of seven years before the chemical investigations were made, and the plants were in their second year of cropping.

(3) The manurial treatments were as follows: farmyard manure; farmyard manure and "complete" inorganic fertilizer (nitrogen, phosphorus and potassium); "complete" bulky organic fertilizer including shoddy; "complete" non-bulky organic fertilizer; "complete" inorganic fertilizer; an organic

manure containing nitrogen and phosphorus, but no potassium ; a control treatment where no manure was given.

(4) The weather during the season of 1931 was abnormally wet, and there was little sunshine. As a result of this the vegetative growth of the plants was exceptionally strong in all plots, but nevertheless differences due to various manurial treatments were very definite, in particular potassium deficient plots being much below the remainder in vigour.

(5) A positive correlation was found between the vigour of the plants and the resulting yields of fruits. The size of the fruits was also examined and it was seen that plants which receive farmyard manure and inorganic fertilizers yielded the largest fruits. Those plots which receive no potassium had the lightest crops and the fruits were also small.

(6) The effects of the manurial treatments on the contents of nitrogen, acid, total sugars, reducing sugars, sucrose, total ash, and certain ash constituents (potassium, calcium, magnesium, phosphorus, sodium, etc.) of the fruits were investigated.

(7) It was found that the effects of the treatments are reflected in the chemical composition of the fruits. The nitrogen content of the fruits decreased over the picking season, and was highest in those fruits from plots which had received inorganic manures. The potassium deficient fruits had a high nitrogen content where nitrogen was given, but the control plot in which both nitrogen and potassium are deficient, yielded fruits with a low nitrogen content. There was a negative correlation between nitrogen content and acidity and also between nitrogen content and total sugars.

(8) Throughout the season the acid content of the fruits fluctuated unevenly, tending to decrease slightly ; the total sugars and sucrose showed a gradual increase, and the reducing sugars varied irregularly.

The acid contents of the fruits were lowest in plots receiving no potassium. The control plot yielded fruit with the highest total sugar content and the highest reducing sugar content. The fruit from the " no potash " plot was lowest in sucrose. No correlation between fruit size and sucrose content could be discovered.

(9) The ash contents of the fruits varied only slightly throughout the season, and the variation was irregular. They were correlated with the manurial treatments, the potassium deficient fruits having an exceptionally low percentage ash and the inorganic fertilizers producing the highest. The ash from farmyard manure alone was on the low side.

(10) The potassium content in the ash decreased during the season, and was lowest in those fruits which had received no potassium in the treatments. There was a positive correlation between the potassium content and the total

ash content, and it was shown that farmyard manure was an efficient source of potassium for the plants. Negative correlations appeared between the potassium content on the one hand and calcium and sodium contents on the other, but the percentages of magnesium and phosphorus showed no discernible relationships to the other elements or to each other. The contents of the latter two elements were approximately constant throughout the season ; the calcium contents were relatively low in the first and second picks and much higher in the third and fourth picks.

(11) The results of the investigation support the field observation that potassium deficiency is an important factor in the problem of the manurial treatment of strawberries on the plots, and show that the applications of potassic fertilizers are clearly reflected in the chemical composition on the fruits.

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(*Received* 15/6/32.)

NOTE ON
THE CYTOLOGY OF PRUNUS ROOTSTOCKS.

By A. A. MOFFETT,
John Innes Horticultural Institution, Merton.

A CYTOLOGICAL examination has been made of the undermentioned forms of *Prunus* with a view to finding out if the chromosome numbers throw any light on their origin. The forms investigated were obtained from the East Malling Research Station and are commonly used as rootstocks for grafting varieties of the plum and allied fruits.

The following are the forms studied and the chromosome numbers found:—

	$2n$ Chromosome Number
Common Plum	48 (Fig. 1)
Common Mussel	48
Broad-leaf Common Mussel	48 (μ)
Narrow-leaf Shiny Mussel	48
Brompton	48 (Fig. 2)
Brussels	48
St. Julien " A "	48 (Fig. 3)
St. Julien " B "	40 (Fig. 4)
Prunus pumila	16 (μ)
Prunus tomentosa	16

Hatton (5) considers that at least four species of *Prunus*, namely *P. domestica, P. insititia, P. cerasifera* and *P. spinosa* are represented in the stocks commonly used. In a later paper (6) he states that such stocks as Brussels, Broad-leaved and Shiny Mussel would be grouped under *P. domestica*, Common Mussel and some St. Juliens as *P. insititia*, and the Myrobolan stocks as *P. cerasifera*. The Myrobolan stocks have been shown to be diploid, $2n=16$ (4) and *Prunus pumila*, a diploid, is reported to have been used as a dwarfing stock for Cordon Plums (cf. Hatton, 6).

The chromosome number of St. Julien " A " agrees with that of *P. insititia*, but St. Julien " B " cannot be the true species with a chromosome number of $2n=40$. The majority of St. Julien stocks are raised on the Continent, and it is stated by Hatton and his colleagues (6) that among the St. Julien and Black Damas seedlings they have on several occasions picked out a range of stocks which would pass botanically as different species. It is very probable that the St. Julien " B " is a seedling resulting from a cross between *P. insititia*, $2n=48$ and a tetraploid form of *P. spinosa*, $2n=32$. Such a cross would give a pentaploid form with the intermediate chromosome number of 2n=40. Similar crosses have been made by my colleague Mr. M. B. Crane at the John Innes Institution and his seedlings had the expected pentaploid chromosome constitution.

The relations between *P. domestica* and *P. insititia* are somewhat obscure. According to Hedrick (7) *Prunus domestica* can be hybridized with other species of Prunus only with difficulty, but a few hybrids between *P. insititia* and *P. spinosa* have been reported. On the other hand, Crane (1) reports that crosses between *P. domestica* and *P. insititia* invariably give a full crop of fruit, showing complete compatibility between the two forms ; and he tells me

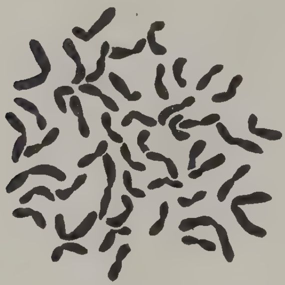

FIG. 1.
Common Plum, 2n=48. Somatic Divisions from Root Tips. ×6,000.

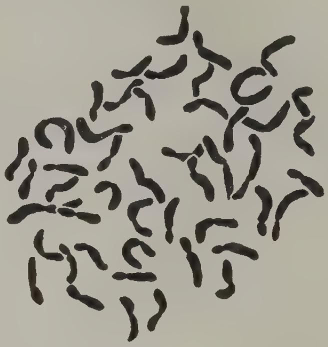

FIG. 2.
Brompton, 2n=48. Somatic Divisions from Root Tips. ×6,000.

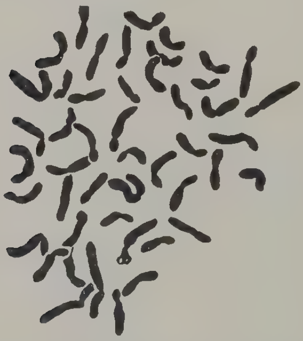

FIG. 3.
St. Julien "A," 2n=48. Somatic Divisions from Root Tips. ×6,000.

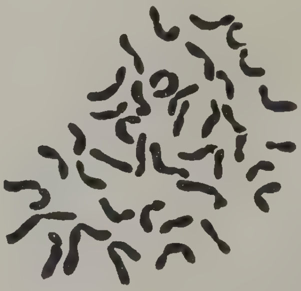

FIG. 4.
St. Julien "B," 2n=40. Somatic Divisions from Root Tips. ×6,000.

that the progeny raised are themselves quite fertile. In his experiments while *P. domestica* × *P. insititia* or the reciprocal cross is highly fertile, *P. domestica* × *P. spinosa* has so far failed. Some seedlings have been obtained from *P. insititia* × *P. spinosa*, but not easily. These seedlings are pentaploid ($2n=40$) as would be expected. Crosses between *P. domestica* and *P. cerasifera* formed fruits ; but the resulting seeds are usually imperfect, and only one seed in seventy germinated. This seedling has 32 chromosomes as would be predicted.

Schneider (8) is of the opinion that *P. domestica* and *P. insititia* are very closely related, probably being only varieties of the same species, and that *domestica* is derived from *insititia*. He considers that *P. insititia* may be derived from a cross between *P. spinosa* and *P. cerasifera*. As a result of their breeding experiments and the interfertility between the above forms of *Prunus*, Crane and Lawrence (3) have also suggested that both *P. spinosa* and *P. cerasifera* may be involved in the origin of *P. domestica*. Whatever the distinction between *P. domestica* and *P. insititia* may be, it is not of the same order as that separating *P. insititia* from *P. spinosa* or *P. cerasifera*. The trees of St. Julien " A " and " B " from which the material was taken for these studies have not yet flowered, but it may be predicted that the fertility of the pentaploid St. Julien " B " would be lower than that of the hexaploid St. Julien " A."

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(*Received* 16/6/32.)

THE INFECTION OF ORANGES BY PENICILLIUM.

By F. MARY GREEN, M.A., PH.D.(CANTAB.),
Newnham College, Cambridge.

I. INTRODUCTION.

1. *Previous investigations on decay.*

Penicillium italicum Wehmer, the blue mould, and *Penicillium digitatum* Saccardo, the green mould, both cause a soft rot of citrus fruits and are responsible for very serious wastage of oranges in transit and storage. The chief characteristics of the rotting have been described by Fawcett (15), and Klotz (23) has made a detailed microscopical study of the mycelium which is confined chiefly to the rind. Wastage due to *Penicillium* has been reported from all orange-growing countries. Barker (4) reports that *Penicillium digitatum* is the chief cause of wastage in oranges arriving in this country, particularly in fruit from Spain where the handling is careless. *Penicillium italicum* develops subsequently in storage. With the possible exception of Spain, all the important orange-growing countries have launched investigations into the conditions governing rotting by *Penicillium* with the object of devising methods to prevent these losses.

Wounds are continually referred to as the most important cause of attack by these fungi. References are given only to some of the more recent reports on the need for the prevention of wounds. Full references to earlier reports will be found in these. Such recent reports have been made in California (Fawcett (15)), in New York (O'Neill and Harriman (27)), in Australia (Young and Read (43), Australian Citrus Preservation Committee (1)), in Palestine (Powell (30)), and in South Africa (Putterill (31), Hahne and Pole-Evans (17)). Well organized careful handling in picking and packing has given good results in reducing the wastage to a minimum.

Given a faulty fruit in the packing case, the infection spreads to other fruits, not only through artificial wounds and through the stem-ends, but also presumably via sound parts of the rind. Both moulds are now regarded as capable of penetrating the uninjured rind and of spreading by contact. Fawcett first claimed this for *Penicillium italicum* (see 15). Subsequently, the power of spreading by contact was demonstrated for *Penicillium digitatum* also (Putterill (31), Tindale and Fish (37)).

External conditions influencing decay have been investigated with a view to discovering the optimum storage conditions for prolonged and healthy dormancy of oranges. Important conditions are temperature (Fawcett and

Barger (14), Kidd and Tomkins (22), Tindale (35, 36), Tindale and Fish (37)), humidity and aeration (Tindale (35, 36)). As regards other contributing causes of decay, Savastano and Fawcett (33) found that ripe lemons were more easily rotted than unripe ones, and Fawcett (15) reported that citrus fruit weakened by long cold storage decayed more readily than fresh fruit.

All workers are agreed that the prevention of wounds is the most important measure to reduce decay, but the dipping of fruit in solutions of certain substances has also been used to prevent wastage. Borax (5-10 per cent) is one such substance, and its use was first described by Fulton and Bowman (16) in California. This was confirmed by Barger and Hawkins (3) in California, Doidge (13) in South Africa, Putterill (31) in South Africa, Young and Read (43) in Australia, Benton (5) in Australia, Takeuchi (34) in Japan, and others. Sodium bicarbonate (Barger (2)) and sodium carbonate (Doidge (13)) are also effective, and they are used in countries where borax treatment is prohibited by law. Tomkins and Trout (38, 39) state that storage of oranges in low concentrations of ammonia or acetaldehyde reduces the amount of decay.

From all these investigations of the conditions governing infection and of the methods of prevention there has grown up a generally accepted picture of the mode of infection of oranges by *Penicillium*. No one has ever claimed that the picture is at all complete, but it seemed to fit in with the available facts. It emphasized that infection depended on the supply of nutrient available to the *Penicillium* being adequate for germination and the maintenance of a sufficiently vigorous growth to penetrate the rind cells. A wound was considered to be the chief channel of infection because it not only formed a means of entry to the rind but also furnished the necessary nutrient. However, given sufficient nutrient to promote vigorous growth, it was supposed that the fungus could penetrate the intact rind, utilizing the stomata as a means of entry. Such a vigorous growth was furnished by a mouldy orange and thus infection by contact was explained. It has also been claimed that infection can occur through uninjured rind provided orange juice is present on the surface. The effect of certain rind characters such as those of particular varieties, ripeness and weakness from long storage were supposed to be due to variations in the amount of nutrient available. Exosmosis of nutrients might occur in very ripe fruit or in weak fruit. The efficacy of borax, bicarbonate, and ammonia in preventing decay was considered to be due to the direct effect of these substances on the growth of *Penicillium*.

To illustrate this conception of the significance of vigorous growth as promoted by nutrients two passages may be quoted. The first is from Fawcett (15):—

> " If punctures or injuries are such as to allow juice to come in contact with the surface, or to run over the fruits, an ideal medium is furnished for the germination and entrance of mould fungi. Juice of lemons was allowed

> to fall upon a lot of other sound lemons. The experiment showed that a large percentage of these fruits, which were subjected to drops of juice, when set aside were later infected with blue and green mould, while other fruit, not so treated, remained sound."

The second is from Putterill (31) and deals with infection through the intact rind:—

> " Given a mould spore on an orange at the edge of a stomatal opening the necessary conditions will have to be present before infection can result. These conditions include, apart from the size of the opening, suitable temperature and atmospheric humidity and a supply of nutriment either within the spore or supplied from without. The supply of nutriment may be absent entirely, or it may be present on the rind as a result of external agencies, e.g. sugar from scale insects, or as a direct result of excretion or of leaching out of the fruit. Should the fungus manage to enter the uninjured fruit, its further growth depends on its ability to penetrate the living cells of the rind. The ease with which it does this will depend on the sources of energy at its disposal ; these in turn are dependent on the permeability to solutes of the cells' protoplasmic membranes."

Putterill then proceeds to describe experiments in which he claims to have obtained infection without a wound using juice as a nutrient.

2. *Aim of the present investigation.*

With the foregoing conception of infection in mind, attempts were made with various nutrients to cause infection through the uninjured rind in order to make microscopical preparations of the means of entry of *Penicillium* into the intact rind. Putterill (31) had suggested the stomata as a means of entry, but he did not record any microscopical preparations to show this. In my preliminary experiments the inoculum of spores in a nutrient was painted on to the surface of the rind with a brush and the oranges were kept at 25° C. under very humid conditions.

Unexpected results were obtained. Using orange juice as a nutrient, often there was no infection, but sometimes there would be several infections on individual oranges. Such infections might be due to the presence of minute invisible wounds. With synthetic media, such as Dox's agar, infection never occurred, although *Penicillium* made good growth in such media. Moreover, the results of experiments on infection by contact were highly erratic and there seemed to be no possibility of forecasting whether there would be infection or not. Such results do not justify the statement that, given an adequate supply of nutrient, *Penicillium* can penetrate the uninjured rind.

It was thought worth while, first to make a detailed investigation of the conditions governing infection via wounds, and then to discover whether it is possible for *Penicillium* to infect the intact rind, or whether natural infection by contact really depends on the presence of minute injuries in the so-called uninjured fruit.

II. TECHNIQUE.

1. *Inoculation of oranges under various experimental conditions.*

In making inoculations the fruit was first surface-sterilized by wiping it with cotton-wool soaked in methylated spirit ; it was then rinsed in distilled water and dried. Three sterile slides were put in position with rubber bands as shown in Fig. 1 (a) and a drop of inoculum was inserted between each slide and the rind with a sterile brush. The slides served to keep the drop of inoculum in position. Care was taken to place the slides on healthy parts of the rind (which were often marked beforehand with an Indian ink cross) and the stem and style ends were avoided. For experiments in which mashed mouldy rind was used as an inoculum, watch-glasses were used instead of slides, the mush being irrigated with water at intervals to prevent its drying out.

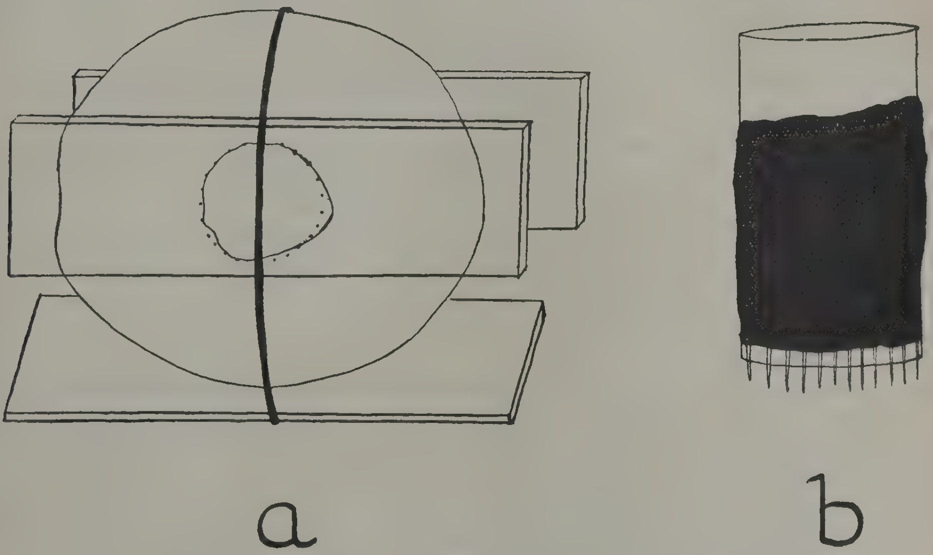

FIG. 1.

a. Orange with slides attached showing circle of pricks and drop of inoculum. (Natural size.)

b. Pricker × 1·5.

The inoculated fruit was kept in an incubator at 25° C. on trays covered with wet cotton-wool and blotting paper. The external conditions were thus optimum for rotting, and none of the results can be attributed to the action of these as controlling factors, although, under natural conditions in storage, they may often exert a marked influence on the amount of decay.

The substances used in the inoculation experiments included water, orange juice, extract of rind in water, synthetic media, and solutions of various acids and alkalies. The most important synthetic media were Brown's solution (Vasudeva (41)), Czapek's solution (Karrer and Webb (21)) and Czapek-Dox glucose solution (Raistrick (32)). In some of the experiments with acids and alkalies solutions of " equivalent " concentrations were used. These were solutions containing the same fraction of the equivalent weight per litre.

Determinations of hydrogen-ion concentration were carried out colorimetrically by Gillespie's Drop Method (see Clark (11)). Gillespie's technique and tables were used throughout, but the graph given by Van Alstine (40) was used for pH values with thymol blue (acid range) as indicator. With juice and rind media modifications had to be made as for coloured fluids. In experiments with mouldy rind pH determinations were made on a concentrated extract in water (12 grammes of rind per 50 cc. water, allowed to stand overnight before filtering), and, by putting indicators directly on to the rind, it was found that the colour approximated to the pH value already obtained for the extract. The pH values for rind may therefore be expressed as those of the extracts. The adjustment of media to various hydrogen-ion concentrations was carried out by the method of Karrer and Webb (21).

The oranges were often subjected to special treatments before inoculation and these are described in the accounts of the experiments. Wounding was a very common treatment and for this special prickers were used. Each pricker was constructed by fastening twenty-four very fine needles on to a glass tube with sealing wax (Fig. 1 (b)). The diameter of the glass tube was about 1·75 cm. and the pricker was pushed into the orange until the end of the tube was flush with the surface of the rind. The depth of the wounds depended on the projection of the needles beyond the end of the glass tube, and, owing to irregularities in the rind, all the wounds would not be of the same depth. However, the use of twenty-four pricks ensured that at least some of them would be of the full depth, as measured by the projection of the needles from the tube. The slides were placed in position immediately after wounding in order to trap any escaping rind-substances and the drop of inoculum was then inserted. Growth of *Penicillium* occurred where the aeration was best (viz. at the edge of the drop) ; hence, since the diameter of the drop usually approximated to that of the pricker, the region of mould growth coincided with the circle of pricks. A series of six prickers was used, by means of which pricks of the following depths could be made in the rind :—less than 0·5 mm., 0·5 mm., 0·75 mm., 1·25 mm., 2·25 mm., 3·5 mm.

2. *Criteria of infection and records of results.*

Numerical comparison of the effects of various experimental conditions on infection was always made on one and the same consignment of oranges because preliminary experiments showed that different consignments often reacted differently to the same condition. The oranges were usually supplied by Messrs. T. J. Poupart, Ltd., of Covent Garden, in cases of 200-300, and they were either Spanish fruit (December to July) or South African fruit (July to December). They were kept in the laboratory until required and were covered with damp cotton-wool to prevent shrivelling.

In the inoculation experiments 3 oranges were used for any one experimental condition, and, since there were 3 inoculations per orange, 9 inoculations were made under identical conditions. It is realized that a sample of 3 fruits is not at all ideal and that the number of infections out of a possible 9 will not stand statistical treatment. However, owing to the necessity of using the same consignment of oranges for comparing the effects of many conditions, it was rarely possible to increase the sample. Provided the results of several experiments agree, the numbers of infections out of 9 are a reliable indication of the effect of the various conditions.

Infection resulted in a definite softening of the rind, easily punctured by the finger. It usually occurred at the edge of the drop of inoculum, sometimes at localized places and sometimes equally all round the edge of the drop. Tables were constructed to show the number of infections occurring under the various conditions three, five, seven, etc. days after inoculation, and although it has only been possible to include a few Tables in this account, all the results of experiments quoted are taken directly from such Tables. With the best conditions for infection softening occurred within three to five days, while, with other conditions, infection failed to take place or did so only after a prolonged period. There was often evidence of some action on the rind in the form of depressed discoloured areas. These may be called " attempts at infection " and often remained so for long periods. Occasionally, however, they were rapidly followed by softening. Such " attempts " were not classed as infections until softening occurred.

The *Penicillia* used in all the inoculations were isolated from one original South African orange, attacked by both *Penicillium italicum* and *Penicillium digitatum*. Spores for inoculations were taken from a mouldy fruit ; a very heavy suspension was employed so that infection was not controlled by the number of available spores (see Savastano and Fawcett (33)). The oranges inoculated with blue and green moulds respectively were kept in separate incubators and great care was taken to keep the two moulds apart. The results recorded for *Penicillium italicum* and *Penicillium digitatum* are always for each mould acting alone, unless a special note is made to the contrary.

III. INFECTION THROUGH WOUNDS.

A. Effect of Depth and Size of Wound.

Using the series of prickers and an inoculum of spores in water, it was found that there was no infection through very shallow wounds, although the spores started to germinate in them. With pricks of increasing depth there were more and more infections until the maximum number (viz. $\frac{9}{9}$) was obtained.

Table I.

Effect of Ripeness.

Egyptian oranges, "Yellow" arrived December, 1931. "Orange" after keeping for about six weeks. Number of infections out of nine.

P. Italicum.

Time after inoculation.		Depth of Prick.			
		0·5 mm.	0·75 mm.	1·25 mm.	2·25 mm.
5 days.	Yellow.	0	1	2	8
	Orange.	0	4	8	9
7 days.	Yellow.	0	1	2	9
	Orange.	0	5	9	9

P. Digitatum.

Time after inoculation.		Depth of Prick.			
		0·5 mm.	0·75 mm.	1·25 mm.	2·25 mm.
4 days.	Yellow.	0	1	6	9
	Orange.	0	3	8	9
6 days.	Yellow.	1	1	7	9
	Orange.	6	7	9	9

Such results are illustrated in Table I. The minimum depth of prick required for 100 per cent infection to occur varied from one consignment of oranges to another. Sometimes a considerable number of infections was obtained through pricks whose depth was less than 0·5 mm.; in other experiments there was little infection until pricks 1·25-2·25 mm. deep were employed.

Ripeness was one factor which influenced the number of infections through shallow pricks. For new season Spanish oranges in a lemon yellow condition there were $\frac{0}{4}$ infections by *Penicillium italicum* and $\frac{1}{4}$ infections by *Penicillium digitatum* through pricks 1·25 mm. deep. It was difficult to carry out a convincing experiment to demonstrate the effect of ripeness by using unripe fruit and ripe fruit of exactly the same variety. Any one consignment of oranges contains some fruits which are very susceptible to infection and others which are particularly resistant ; most of the fruits are intermediate between the two classes. If oranges were sent from Spain or elsewhere in various stages of ripeness it usually happened that the ripest consignment had a very large percentage of decay on arrival whereas the unripe consignment was still perfectly sound. Although this indicates that ripe fruit decays more readily than unripe fruit, the remaining ripe oranges were not fit for laboratory experiments. For it would not be fair to compare a normal random sample from the unripe consignment, containing susceptible, intermediate and resistant fruits, with the remaining ripe fruits which must be considered as belonging to the resistant class, the susceptible and intermediate fruits having decayed in transit. It was therefore impossible to demonstrate the mean susceptibility to infection through wounds of the ripe consignment for comparison with that of the unripe consignment. Experiments of this kind should be carried out in the actual orange-growing districts.

An alternative method was to obtain unripe fruit and ripen it in the laboratory by keeping it in ventilated boxes covered with damp cotton-wool to prevent shrivelling. Table I shows the infections obtained with Egyptian oranges on their arrival and after being kept for six weeks. When they arrived they were yellow and hard, but, after the ripening period, they had become orange and rather more plastic ; the riper fruit showed a marked increase in the number of infections through shallow minute wounds.

The effect on infection of different depths of wounds might be due to the varying characters of the rind regions penetrated. There are three important regions in the rind (Fig. 2):

(*a*) The epidermis has a very thick cuticle and is punctured by stomata (see Fig 3).

(*b*) The yellow rind (" flavedo " of American authors) is the region containing the oil glands, and consists of closely compacted regular cells (Fig. 4 (Y)), the outermost of which contain numerous chromoplasts. The whole tissue is firm and compact and its depth, which is fairly constant in all types of oranges, is 1-1·5 mm. There is a gradual transition to the third region.

(*c*) The white rind (" albedo " of American authors) has a very variable depth according to the total thickness of the rind. A thick-skinned orange has about the same depth of yellow rind as a thin-skinned one, but the former has a considerably thicker white rind. The white rind is a soft spongy tissue and consists of loosely arranged cells with pitted walls (Fig. 4 (W)). The tissue contains numerous air spaces and is supplied by vascular bundles.

Since infection fails to occur through minute wounds which penetrate only the outer parts of the yellow rind, one might attribute this to the inhibitory influence of the yellow rind constituents on the growth of *Penicillium*. In a rotten orange the hyphæ always avoid the oil cavities, and hence, if the wound penetrates an oil cavity, it is probable that germination is inhibited by orange oil. However, many of the shallow wounds, through which infection failed to occur, did not puncture oil cavities and there is no evidence that the other constituents of the yellow rind inhibit growth. On the contrary a water extract of the outer yellow rind supported a luxuriant growth of *Penicillium*. Another possibility is that lack of nutrient prevents infection through shallow minute wounds, i.e. that there is enough nutrient exuded to start germination, but that this is not sufficient to promote the vigorous growth necessary for infection. Infection occurred readily through shallow sliced areas in the outer yellow rind; in this experiment comparatively large areas of yellow rind were exposed from which there was considerable exudation of yellow rind substances. If infection through wounds depends on the amount of nutrient available to promote the growth of the fungus, then the addition of any nutrient should promote infection through shallow minute wounds. Experiments were made to test this.

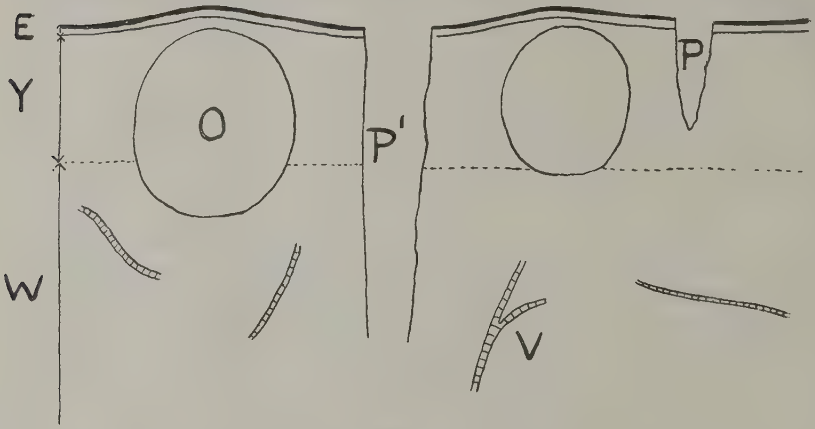

FIG. 2.

Diagram of the regions of the rind. E, epidermis; Y, yellow rind; W, white rind (only the outer part shown); O, oil cavity; V, vascular supply of white rind; P, shallow prick; P¹ deep prick.

×22·5 approx. Epidermis exaggerated.

B. PROMOTION OF INFECTION THROUGH SHALLOW MINUTE WOUNDS.

In the experiments on the promotion of infection through minute wounds pricks of less than 0·5 mm. in depth were used, and usually the pricks were dried out for a day or two before inoculation. This ensured that there would not be any infections in the control fruits inoculated with spores and water. The prevention of infection by the drying out of wounds will be described later.

1. *Orange juice and rind extract.*

Using the series of prickers it was found that orange juice caused infection even through minute wounds less than 0·5 mm. deep (see Table III). When various dilutions of juice with water were employed it was found that the more dilute the juice the deeper the wound required for infection. Rind extract in water also promoted infection (Table II), but it was not as efficient as orange juice.

That the presence of juice or rind extract enables infection to occur through very minute injuries (which would otherwise remain sound) was neglected in the evidence put forward by Putterill (31) for the ability of *Penicillium* to penetrate the uninjured rind. For example, he investigated a case of oranges which had had very rough treatment and showed a large percentage of decay. He selected 66 sound fruits which were wet owing to contamination with juice and rind from mouldy oranges, and 101 dry fruits. He found that all the wet fruits were mouldy after twenty-one days, whereas only 19 of the dry fruits were mouldy ; this was regarded as evidence for the penetration of *Penicillium* without a wound. Considering that all the oranges had had rough handling, the possibility cannot be excluded that all had slight injuries and that in the wet fruits the presence of rind and juice enabled infection to take place through these injuries.

2. *Synthetic media.*

Although the results with rind extract and orange juice support the theory that infection through minute wounds depends on the amount of nutrient available to the fungus, synthetic media did not promote infection, or did so only after a prolonged period (see Table II for results with *Penicillium italicum*). Such synthetic media included Brown's solution, Czapek's solution and Czapek-Dox glucose medium. The growth of *Penicillium digitatum* in such media was much inferior to that in orange juice and there was an initial lag before any growth took place. It has been shown that the green mould has great difficulty in using either nitrate or asparagin as a source of nitrogen (Raistrick (32), Marloth (24)). Ultimately, there was fairly good growth, but possibly it may be urged that the failure of the green mould to infect from synthetic media may be due to lack of vigorous growth especially in the initial stages. However,

TABLE II.

Very Shallow Pricks (less than 0·5 mm. deep). Effect of Rind Extract, Synthetic Media, Ammonium Oxalate and Citric Acid.

Pricks dried two days. South African oranges. August, 1931. Number of infections out of nine.

P. Italicum.

Time after inoculation.	Water.	Rind Extract.	Brown's Solution.	Czapek-Dox Glucose Solution.	Ammonium Oxalate.		Citric Acid 5%
					0·5%	5%	
3 days.	0	1	0	0	0	9	9
5 days.	0	4	0	0	2	9	9
7 days.	0	4	0	2	4	9	9
9 days.	0	6	1	2	4	9	9

Penicillium italicum made uniformly good and vigorous growth in the synthetic media, and hence, for the blue mould at least, vigorous growth is not the whole story of infection through minute wounds.

3. *Acids.*

In one of the experiments with synthetic media the effect of adding 0·2 per cent citric acid was investigated, and it was found that the acid solutions were effective in causing infection. Subsequently, it was found that various concentrations of the acid alone (without the nutrient substances of the synthetic medium) were effective, and that other acids such as malic, oxalic and sulphuric also promoted infection. Table III shows one set of results ; it will be seen that the more concentrated citric acid solutions were more potent than the dilute ones, and that, considering concentrations " equivalent " to 5 per cent citric acid, oxalic acid and sulphuric acid were superior to malic acid and citric acid.

The growth of *Penicillium* in solutions of such acids was tested in specimen tubes, and it was found to be practically negligible. The spores of *Penicillium italicum* became swollen in all the acids, but only in the more dilute citric acids were there any germ tubes, and, even then, the growth was extremely feeble. *Penicillium digitatum* never produced any germ tubes in any of the acids, although the spores became swollen. The beneficial effect of acids on infection was evidently not due to a direct nutrient effect on the fungus. Using the slide technique, oranges were treated with citric acid for four days, and then they were washed thoroughly in running water to remove the acid. Some of the treated fruit was inoculated with spores in water and some with spores in acid, but all of it became infected, thereby demonstrating that the initial treatment with citric acid had enabled infection to take place. The beneficial effect of acid on infection must be due to direct action on the rind.

In general, the stronger the acid, i.e. the greater its hydrogen-ion concentration, the greater is its action on the rind ; on the other hand the stronger the acid the more difficult is it for *Penicillium* spores to germinate. The acid solution diffuses into the rind, and the actual concentration of acid in the outer layers of the rind will, of course, be less than that in the pure solution ; hence growth of *Penicillium* may be just possible in the acid-soaked rind, although in the pure solution in a specimen tube no growth takes place. If rotting is to occur the hyphæ must be able to attain the limit of the acid-soaked area in order to cause normal softening beyond. The results with strong acids demonstrate clearly the antagonism between the effect of acid on the rind and the effect of

TABLE III.

Very Shallow Pricks (less than 0·5 mm. deep). Effect of Acids and Orange Juice.

Other acids approx. " equivalent " to 0·2% citric acid. Spanish oranges. February, 1931. Number of infections out of nine. For figures in brackets see text.

P. Italicum.

(Pricks dried 2 days before inoculation.)

Time after inoculation.	Water.	Citric Acid.				Malic Acid. 0·2%	Oxalic Acid. 0·2%	Juice.*	" Neutralized " juice.*
		0·02 %	0·2 %	1 %	5 %				
3 days.	0	0	0	3	2(5)	0	0	6	0
6 days.	0	0	6	9	8	0	3	6	2
10 days.	0	0	6	9	8	3	7	—	—

* Pricks inoculated at once.

P. Digitatum.

(Pricks inoculated at once.)

Time after inoculation.	Water.	Citric Acid.				Malic Acid. 0·2%	Oxalic Acid. 0·2%	Juice.	" Neutralized " juice.
		0·02 %	0·2 %	1 %	5 %				
3 days.	0	2	4	8	5(9)	2	2	6	0
6 days.	2	3	8	8	9	6	4	9	2

Penicillium. Infection is often delayed and preceded by large depressed areas on the rind which represent the stage in which the hyphæ are still confined to the acid-soaked regions. In the tables a number in brackets indicates the number of infections counting those in which the hyphæ are still in the acid-soaked areas.

4. *Conception of a resistance in the outer rind.*

It seems reasonable to suppose that there exists a resistance to infection in the outer yellow rind. It is broken down by acids and also by something produced by the growth of *Penicillium* in orange juice and rind. On the other hand, growth of the fungus in synthetic media does not result in the breaking down of resistance. Hence the old nutritional conception of infection which emphasizes vigorous growth of the fungus as the important factor cannot be accepted. Vigorous growth is by no means concomitant with the production of a resistance-destroying system. The latter is produced by growth in orange juice and rind, but not in synthetic media.

The question at once arises as to whether the beneficial effect of rind and juice is due to acids. Juice contains citric acid, and it was found that, by adding sodium carbonate to juice, infections were greatly reduced (see " neutralized " juice in Table III), although the fungus made good growth in the " neutralized " juice. Both rind and juice become more acid after the growth of *Penicillium* and it seemed possible that the resistance-destroying system consisted of acid alone. The subject will be discussed later but, for the time being, it may be said that by adding acid to Czapek's solution to make its pH equal to that of mouldy rind or mouldy juice no infection occurred through shallow minute wounds. It is unlikely then that acidity is the only factor in the resistance-destroying system.

C. PREVENTION OF INFECTION THROUGH DEEP WOUNDS.

1. *Drying out.*

Not only was it possible to promote infection through shallow minute wounds, but by various treatments infection through deep wounds could be prevented, although, under normal conditions, 100 per cent rotting would have occurred. One such treatment was by drying out the wounds for several days before inoculation. For *Penicillium italicum*, using spores in water and wounds 3·5 mm. deep, there were always $\frac{9}{9}$ infections after three days if the pricks were inoculated at once, but, if the pricks were dried out for seven days before inoculation, there was no infection after four days and only $\frac{1}{9}$ infections after seven days. The drying out process renders the normally susceptible white rind resistant to infection, but the resistance is overcome by using an inoculum of spores in juice. The presence of juice caused $\frac{9}{9}$ infections through dried out wounds. Similar results were obtained for *Penicillium digitatum*.

2. *Alkaline substances.*

Infection through deep pricks was prevented by using an inoculum of spores in certain alkaline substances. Marloth (24) has made a detailed study of the influence of the hydrogen-ion concentration on *Penicillium* with reference to the effect of sodium bicarbonate and other substances on the fungus. He concluded that the hydroxyl-ion concentration of his sodium bicarbonate solutions was not sufficient to account for the great reduction in germination and growth which they caused, and he therefore postulated a direct toxic action of the bicarbonate ion. According to him, in an orange which has been dipped in sodium bicarbonate, the *Penicillium* spores on the rind start to germinate and become immersed in a saturated solution of sodium bicarbonate, formed from the thin film of this substance left on the rind after treatment. He says: "The bicarbonate ion acts on the protoplast of the thin walled germ tube or on the spore at the spot at which the wall is weakened for the emergence of the tube, death resulting."

By using "equivalent" concentrations of borax, sodium carbonate and caustic potash it was found that, as compared with a water inoculum, the first was the most potent in reducing infection by *Penicillium italicum* through deep wounds. Thus, spores in water gave $\frac{9}{9}$ infections after three days through pricks 2·25 mm. deep, whereas, even after five days there were no infections by spores in 13 per cent borax and $\frac{3}{9}$ infections by spores in 6·6 per cent borax. The other two substances also reduced infection, although to a lesser extent than borax, and sodium carbonate was almost as effective as caustic potash in spite of the much greater hydroxyl-ion concentration of the latter. These results support Marloth's view that alkaline substances do not act solely by virtue of their hydroxyl-ion concentrations and that other ions may be important. For example, he stressed the importance of the bicarbonate ion in his sodium bicarbonate solutions; in my experiments with borax and sodium carbonate the borate and carbonate ions are the important ones.

So far, my results corroborate Marloth's views, but it is important to note that alkalies did not prevent infection through deep wounds indefinitely. After nine days there were a considerable number of infections, especially with sodium carbonate and caustic potash; consequently alkalies delay infection rather than prevent it. Apparently infection is possible after the alkali has leaked away through the wounds into the rind. It is unlikely that the *Penicillium* is killed by the alkalies; otherwise it is difficult to account for the fungus causing infection after the initial delay. It is more likely that rotting is temporarily inhibited by the alkalies, and this view gains support from similar results of contact experiments. Infection by contact was delayed by the presence of alkali, but it occurred after an initial lag as soon as the rind and juice exudations had diluted the alkali.

As regards the use of sodium bicarbonate commercially, it is important in preventing the infection of the first orange in the case, assuming that there are only minute injuries and that the sole sources of infection are casual spores on the rind. Such prevention may consist in a definitely toxic action on the part of the bicarbonate ion, as postulated by Marloth, or in a permanent inhibition of growth. For infection through deep wounds and by contact there is no permanent action by bicarbonate, which can only delay rotting and is powerless to prevent it.

As regards the prevention of infection through wounds by ammonia gas, Tomkins and Trout (38) report that, if absorption of ammonia by mouldy fruit takes place, control can only be temporary. In both the ammonia and acetaldehyde treatments (Tomkins and Trout (38, 39)) the prevention will be more permanent than that obtained by bicarbonate and borax, only as long as there is a continual supply of gas to replace that lost by absorption. For the ammonia treatment, ammonium bicarbonate crystals are packed with the fruit but, in time, these will all volatilize.

IV. INFECTION THROUGH THE UNINJURED RIND.

A. Effect of Artificial Treatments.

1. *Chloroform.*

Infection through the uninjured rind was possible if the oranges were first treated with chloroform. The fruit was subjected to chloroform vapour for six hours or more ; it was then washed in running water and inoculated with spores in water or in orange juice. Infection took place readily with either inoculum without the presence of a wound. On being removed from the chloroform the oranges were flabby and were covered with yellow exuding drops, as though the semi-permeable properties of the rind had been destroyed. Moreover, the contents of the cells of the yellow rind were seen to be homogeneous and yellow, without separate plastids. After a day or two the fruit became brown. It is obvious that exposure to the anæsthetic is an extreme treatment which has no parallel in natural storage conditions. Even if natural infection by contact can take place without wounds, artificial treatment with chloroform is not likely to provide the clue as to what conditions are necessary for contact infection.

2. *Acids.*

It was found that acids enabled infection to occur through the uninjured rind. Evidently, provided the resistance of the outer yellow rind is overcome, infection can occur without wounds. Microscopical preparations were made of oranges which had been steeped in 5 per cent citric acid for five days and then washed and inoculated with *Penicillium italicum*. Fig 3 shows that in preparations made twenty-four hours after inoculation all the hyphæ in the rind can be traced to stomata. Thus, for infection without a wound, the stomata are the natural means of entry. There was no sign of cuticular penetration.

The general effects of acids on infection (Table IV) proved to be much the same as their effects on infection through minute wounds. Inoculations were made using various concentrations of citric acid and also acetic, malic, tartaric, oxalic, sulphuric, nitric and hydrochloric acids. As would be expected, a stronger acid was required for infection through the uninjured rind than for infection through minute wounds. The results showed that acid has a dual effect, due to the antagonism between its action on the rind and its action on *Penicillium*. Citric and tartaric acids are of about equal strength, but *Penicillium italicum* made better growth in the latter, and, correlated with this, there were more infections from tartaric acid than from citric acid (using "equivalent" concentrations). With the mineral acids and the more concentrated citric acid solutions, infection occurred only after a lag, which represented the time required for the hyphæ to grow through the depressed acid-soaked areas. That the promotion of infection by acids is due to direct action of the acid on the rind was demonstrated by the results of an experiment in which the oranges were

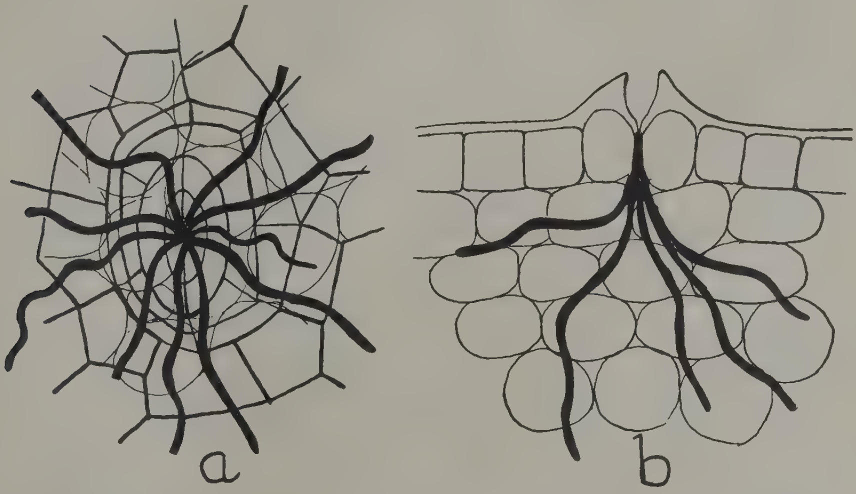

FIG. 3.

Sections through the rind of an orange which was treated with 5 per cent citric acid (five days) and then inoculated with *Penicillium italicum*.

Diagrams represent the rind twenty-four hours after inoculation.

a. Surface section. b. Vertical section. ×900 approx.

TABLE IV.

No Wound. Effect of Acids and Juice.

Other acids approx. "equivalent" to 1% citric acid. Spanish oranges. May, 1931. Number of infections out of nine.

"Deps" = depressed areas. Figures in brackets have same significance as in Table III.

P. Italicum.

Time after inoculation.	Water.	Citric Acid.			Malic Acid. 1%	Oxalic Acid. 1%	Sulphuric Acid. 0·46%	Juice.		Lemon Juice.
		1%	2·5%	5%				Normal.	Plus 4% Citric Acid.	
4 days.	0	0	3	3	0	0	3 (5) deps.	0	6	2
6 days.	0	6	6	8	0	4	7	1	9	8
8 days.	0	7	7	9	0	6	8	5	9	9

P. Digitatum.

Time after inoculation.	Water.	Citric Acid.			Malic Acid. 1%	Oxalic Acid. 1%	Sulphuric Acid. 0·46%	Juice.		Lemon Juice.
		1%	2·5%	5%				Normal.	Plus 4% Citric Acid.	
4 days.	0	2	3	3	0	0	4(5) deps.	3	3	8
6 days.	0	5	6	6	2	3	8	5	9	9
8 days.	0	7	7	9	3	4	9	7	9	9

treated with acid and were then washed thoroughly before inoculating with spores and water. The acid-treated fruit was readily infected, but, in water-treated control fruit infection failed to occur, even if the spores were provided with a nutrient (Brown's solution).

3. *The resistance of the outer rind in relation to artificial treatments.*

All the results of inoculations of minute wounds and of the uninjured rind had confirmed the provisional hypothesis that there exists a resistance to infection in the rind. This resistance decreases progressively from without inwards, and can be artificially increased or decreased by certain treatments. It is necessary to correlate the resistance in the outer rind with definite characters of the fruit and to discover how acids and chloroform break down the resistance.

Our knowledge of the biochemical composition of oranges is still fragmentary and much of the available information is derived from purely commercial studies of orange products (McNair (25, 26)). The rind has a framework of pectic substances with a certain amount of hemicellulose and contains sugars and a glucoside, hesperidin, as well as orange oil, the last named being confined to the oil cavities. These only represent some of the more important constituents of rind and juice for both contain several other important constituents in very small quantities such as oxidizing enzymes (see Onslow (29)) and vitamins (Willimot and Wokes (42)).

The resistance of the outer rind is not due to growth-inhibiting substances, because it has already been shown that the constituents of the yellow rind, apart from the orange oil, which is localized, are capable of supporting a luxuriant growth of *Penicillium*. The resistance is more likely to be associated with the special physiological characters of the cells and their walls.

The cell walls of the yellow and white rind contain a considerable amount of pectic substances. No complete analysis of the other wall constituents has been made, but there may be other carbohydrate complexes present, particularly in the walls of the yellow rind. Hemicellulose, defined as that portion of the wall soluble in normal caustic soda and precipitated by alcohol, is certainly present (Clayson, Norris and Schryver (12)). It was found that the state of the pectic substances in yellow and white rinds differed. The standard nomenclature for pectic substances proposed by Carré (9) has been followed, and in all the experiments the standard tests for pectin were carried out (see Onslow (28)). A water extract of the white rind gave a copious precipitate of pectin with alcohol, whereas a water extract of the outer yellow rind gave no precipitate. Thus, the loose spongy nature of the white rind is associated, not only with many air spaces, but also with a large proportion of soluble pectin. The walls are therefore soft and easy to penetrate. On the other hand, the firm compact yellow rind has no soluble pectin and its walls are likely to be resistant to penetration by a fungus.

When thin slices of the yellow rind were treated with acids they became soft and pliable and this was associated with a copious production of soluble pectin and with the swelling of the walls. In the stronger acids these changes were brought about in a few hours, while control slices, treated with alkali or water, gave negative results for pectin. The breaking down of the rind-resistance by acids is thus associated with the softening of the hard cell walls of the outer yellow rind by the hydrolysis of the insoluble precursor of pectin. Since this is one way of breaking down the resistance, one would expect that other substances, capable of causing pectic hydrolysis, ought to promote infection. Ammonium oxalate is such a substance and Table II shows that it was effective in promoting infection through minute wounds. As regards infection through the uninjured rind, the number of infections out of 9 for *Penicillium digitatum* spores in water, 5 per cent citric acid, 2·5 per cent ammonium oxalate and 5 per cent ammonium oxalate respectively were 1, 6, 8 and 9 after five days.

Treatment with chloroform was not associated with the production of soluble pectin in the outer rind. However, in a chloroformed orange the cells are dead, the semi-permeability of the protoplasm having been destroyed. It is small wonder that *Penicillium* can penetrate such a dead decomposing rind whose walls are thoroughly soaked in nutritive rind substances. Thus the breaking down of the resistance by chloroform is associated with the extreme changes following on the action of the anæsthetic.

The effect of acids, ammonium oxalate and chloroform suggest that the resistance of the outer yellow rind is mechanical in nature. It may be due either to cell turgor or to the hardness of the walls. Softening of the walls by acids and ammonium oxalate inevitably means a decrease in turgor also, so that it is difficult to separate the two effects. Chloroform causes loss of turgor without pectic hydrolysis of the walls, but the loss of turgor is accompanied by loss of semi-permeability and by other autolytic changes. It would be interesting to discover whether resistance could be destroyed simply by loss of turgor without any other changes such as wall-softening or loss of the semi-permeable properties of the rind. The use of plasmolysing solutions involve the soaking of the rind walls in the particular solution used, and, so far, it has not been possible to decrease the turgor of the rind without introducing other complications.

B. EFFECT OF ORANGE JUICE AND ORANGE RIND IN RELATION TO NATURAL INFECTION BY CONTACT.

1. *Infection with the aid of orange rind and juice.*

By using an inoculum of juice or rind from a recently rotted orange infection was readily obtained without the presence of a wound. Table V compares the effect on infection by *Penicillium italicum* of juice and mashed rind from a healthy fruit with that of the same products from a recently infected mouldy fruit. The numbers of infections with the mouldy media were too many to lead one to suppose that they depended on the presence of casual microscopic wounds. Hence, it may be concluded that mouldy orange media are really capable of promoting infection without a wound, and that natural infection by contact does not necessitate the presence of minute wounds in the healthy fruit. The stomata are probably the means of entry, but preparations to show stomatal entry have only been made for acid-treated fruit and not, as yet, for natural infection by contact.

Juice and rind from old mouldy oranges were less effective in causing infection, and Table VI shows the effect of the age of the mouldy rind inoculum

TABLE V.

No Wound. Effect of Rind and Juice from Sound Fruit and Recently Rotted Fruit.

South African oranges. October, 1931. Number of infections out of nine.

P. Italicum.

Time after inoculation.	Water.	Rind.*		Juice.	
		Sound.	Mouldy.	Sound.	Mouldy.
5 days.	0	0	3	1	6
7 days.	0	0	7	2	7
13 days.	0	1	7	3	7

* Oranges kept under bell jars in the incubator to prevent drying out of mashed rind.

TABLE VI.

No Wound. Effect of Mouldy Rind of Various Ages.

Spanish oranges. January, 1932. Number of infections out of twelve.

P. Italicum.

Time after inoculation.	3 days.† pH 3·25	7 days. pH 3·2	11 days. pH 3·4	15 days. pH 4·1	20 days. pH 4·7
5 days.	7	7	0	1	0
7 days.	12	12	6	2	—
9 days.	12	12	8	7	6
14 days.	12	12	12	12	10

† Owing to lack of material pH determination not made on same individual oranges as used for inoculation. This *only* applies to 3 days rind (*P. italicum*).

P. Digitatum.

Time after inoculation.	3 days. pH 3·2	7 days. pH 3·7	11 days. pH 4·5	15 days.* pH 5·0	20 days.*
4 days.	5	2	1	0	0
5 days.	9	8	1	0	0
7 days.	12	10	1	2	0
9 days.	12	10	4	4	2

* Mouldy rind contaminated with blue mould.

on infection. The same mouldy oranges were used as sources of inoculum throughout so that the number of stages is limited. It will be seen that the power of infecting sound fruit fell off with increasing age of the mouldy rind. Old mouldy rind caused "attempts at infection" (see section on Technique) which became soft later. Now young mouldy rind has greatly enhanced acidity (pH about 3·1-3·3) compared with sound rind (pH about 5·3-5·6), but the acidity falls off again as the mouldy rind becomes old (see Table VI). Thus, the power of infection of mouldy rind is inversely proportional to its age and directly proportional to its hydrogen-ion concentration. It will be noticed that, for rind decayed by the green mould, the infecting power and also the hydrogen-ion concentration fell off more rapidly than for rind decayed by the blue mould.

The effect of the age of the mouldy rind on infection accounted for the erratic results obtained in the preliminary contact experiments ; probably infection occurred only from young mouldy fruit. This was confirmed by a contact experiment in which mouldy oranges of known ages were used as inocula. Infection took place from the three and eight days old mouldy fruit, but not from twelve, sixteen, and twenty-two days old mouldy fruit. In this connection Tindale and Fish (37) reported that infection takes place by the spread of the white mycelial growth on the mouldy orange, and that oranges placed against a mass of spores (as distinct from white mycelial growth) do not go mouldy. In nearly all my experiments on contact the fruit was either packed tightly in a box, or the sound and mouldy oranges were fastened together in pairs by means of broad rubber bands ; if the oranges were merely arranged in a row without any pressure at all, there was usually no infection. Under natural conditions, of course, the fruits are pressed against one another in the case.

2. *The breaking down of rind-resistance by* Penicillium.

The question now arises as to how *Penicillium*, growing on a recently rotted orange, breaks down the resistance of a sound fruit. Is the breaking down of resistance due to the enhanced acidity of the mouldy orange ? The experiment in which different ages of mouldy rind were used for inoculation would indicate this, and, moreover, by adjusting young mouldy rind to different hydrogen-ion concentrations, it was found that infection was directly proportional to hydrogen-ion concentration. Similarly Table IV shows that fresh lemon juice (pH about 2·2) was more effective than fresh orange juice (pH about 3·6) in promoting infection without a wound, and that the addition of citric acid to orange juice increased its efficacy. It was also found that orange juice to which sodium carbonate had been added did not induce infection.

Thus, the acidity of a mouldy orange is an important factor in causing infection without a wound. But is it the only factor concerned in the breaking down of rind-resistance ? Synthetic media do not promote infection, and, if acid is the only factor concerned in the breaking down of resistance by a mouldy orange, one would expect that the addition of acid to a synthetic medium to make its pH equal to that of a mouldy fruit (pH 3·1-3·3) would enable infection to occur. A series of Czapek's solutions of graded hydrogen-ion concentration was prepared, and this series was used for inoculations through shallow minute wounds and through the uninjured rind. Infection through the uninjured rind did not take place above pH 1·8, and for shallow minute wounds pH 2·5 was the upper limit. Germination tests showed that in the solutions promoting infection there was practically no growth, and it was evident that Czapek's solution is only effective in causing infection when its free acid content is sufficient to act on the rind in the same way as does pure citric acid solution. Now even the most acid mouldy rind has a pH of not less than 3 and Czapek's solution of this acidity did not promote infection. It is true that there is still considerable doubt as to the effect of the growth of *Penicillium* on the hydrogen-ion concentration of the various synthetic media, so that the initial value pH 3 may not represent the final value after growth of *Penicillium*. Thus, lest it be argued that the experiments with Czapek's solution are not sufficient to show that acid alone is not the key to contact infection, there is other evidence bearing on the matter. Five per cent citric acid readily promotes infection, and if small pieces of rind are steeped in this acid they become soft and macerated. Young mouldy rind equally promotes infection, but the liquid squeezed out of it after pounding with sand does not cause any appreciable softening of the pieces, although its hydrogen-ion concentration is the same as that of the mouldy rind. Lastly, very dilute citric acid (e.g. 0·5 per cent) does not usually promote infection through the uninjured rind or causes only a few infections ; yet its hydrogen-ion concentration (about pH 2·3) is greater than that of young mouldy rind (pH 3·1-3·3) which causes 100 per cent infection.

Acid alone does not account for the breaking down of rind-resistance by *Penicillium*, although it is one factor in the resistance-destroying system which is produced by the fungus on orange rind and juice but not on synthetic media. If we knew more about the effect of *Penicillium* on the rind it might be possible to define the other factor or factors in the resistance-destroying system, for the latter must be produced in the rotting process.

It was possible to investigate the effect of *Penicillium* on the pectic substances of the rind by staining with ruthenium red and Figs. 4, 5 and 6 illustrate the changes which occur in the cell walls of the white rind (W) and the yellow rind (Y) as rotting proceeds. Microscopical preparations were made of sound rind (a) and of all stages of rotting from the young soft zone (b), through the region with emerging conidiophores (c), to the region of old conidiophores (d). At the edge of the soft zone the walls of the white rind are enormously swollen so that the whole of the white rind consists almost entirely of a matrix of swollen walls, which have expanded into the air spaces and the lumina of the cells. (Compare a(W) in Fig. 4 and b(W) in Fig. 5.) The staining with ruthenium red is now less dense, showing that the walls are undergoing decomposition into something other than pectic substances. A few hyphæ ramify in the wall matrix and apparently cause dissolution as they grow. The walls of the yellow rind are unchanged in the soft zone, but in the region with emerging conidiophores, when they are penetrated by hyphæ, they become swollen and are densely stained with ruthenium red except round the pits. (Compare a(Y) in Fig. 4 with c(Y) in Fig. 5.) The swelling is not nearly so great as that in the white rind. In old infected fruit (d in Fig. 6) both yellow and white rinds are riddled with hyphæ which have caused dissolution of the walls ; there are only traces of cell walls in the yellow rind (Y) and walls are absent from the white rind (W) except for the vascular tracheids.

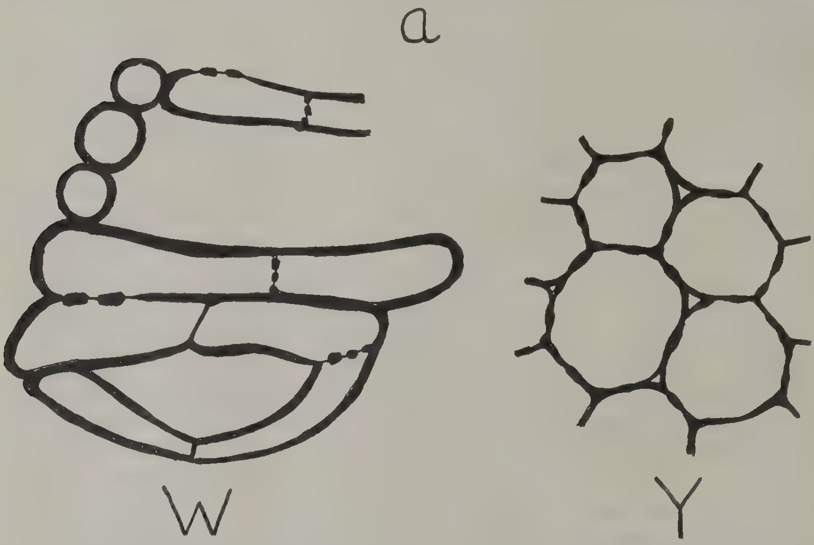

FIG. 4.

a. Cells of the white rind (W) and the yellow rind (Y) from the sound region. Walls stained with ruthenium red shown black. ×380 approx.

Ruthenium red only shows the effect of *Penicillium* on the pectic substances of the wall and the effect on the other possible constituents has not yet been investigated. The walls of the yellow rind certainly seem to have an undissolved residue. As regards its action on the pectic substances, *Penicillium* resembles acids in that it brings about pectic decomposition, thereby softening the walls, but, whereas acids simply cause hydrolysis into soluble pectin, *Penicillium* carries the decomposition much further and ultimately brings about wall dissolution.

It might be thought probable that pectic enzymes are concerned in the rotting process and that they constitute the other factor in the resistance-destroying system. However, so far, all attempts to make extracts of the rotted fruit which show enzyme action have been unsuccessful. *Penicillium* does not show any action in advance of its growth for hyphæ are present at the limit of the soft zone. Thus, rotting is very closely associated with the tips of living hyphæ, and if enzymes are concerned they are likely to be closely bound to the living protoplasm and difficult to detach from it. Klotz (23) prepared an extract from *Penicillium*, which, he said, caused a certain amount of softening when injected into sound oranges, but, so concerned was he in looking for an acid or some other known substance in the extract, that he did not even make injections with boiled extracts to see if an enzyme was present.

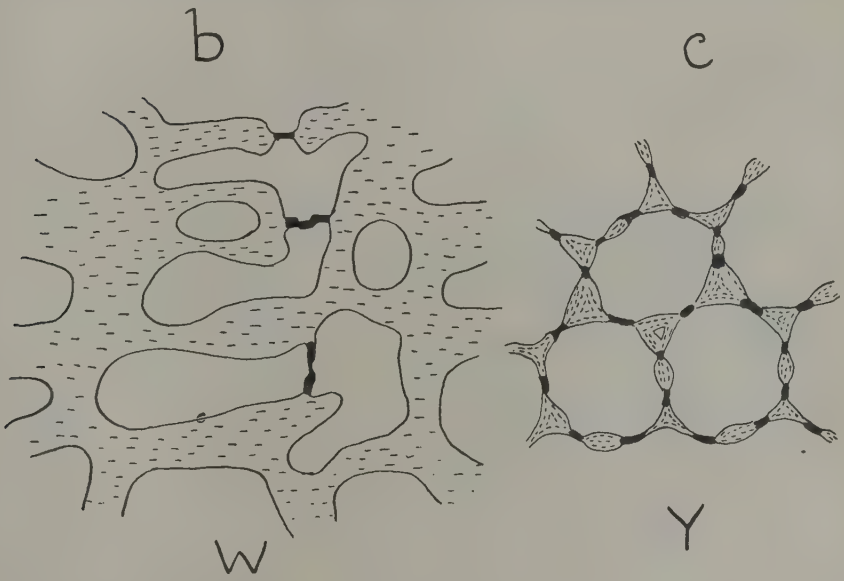

FIG. 5.

b. Cells of the white rind (W) from the edge of the soft zone.

c. Cells of the yellow rind (Y) from the region with emerging conidiophores.

Walls stained with ruthenium red shown black; walls staining only faintly with ruthenium red shown with line shading. ×382 approx.

The work of previous investigators on fungal rotting has shown that it is dangerous to generalize on the mechanism of rotting ; each fungus must be considered separately. Brown (6, 7, 8) showed that a pectic enzyme system is responsible for the maceration and death of the cells in the rotting caused by *Botrytis cinerea* and that there is no separate action of an acid apart from this system. On the other hand, Johann (20) found that the injury to maize seedlings caused by *Penicillium oxalicum* is due primarily to the oxalic acid secreted by the fungus. Lastly, Harter and Weimer (18, 19) found that the mechanism of rotting of sweet potatoes by *Rhizopus tritici* varied with the nutrient. It was caused by "pectinase" when the fungus was grown on natural media containing pectin, and by acids alone when it was grown on synthetic media.

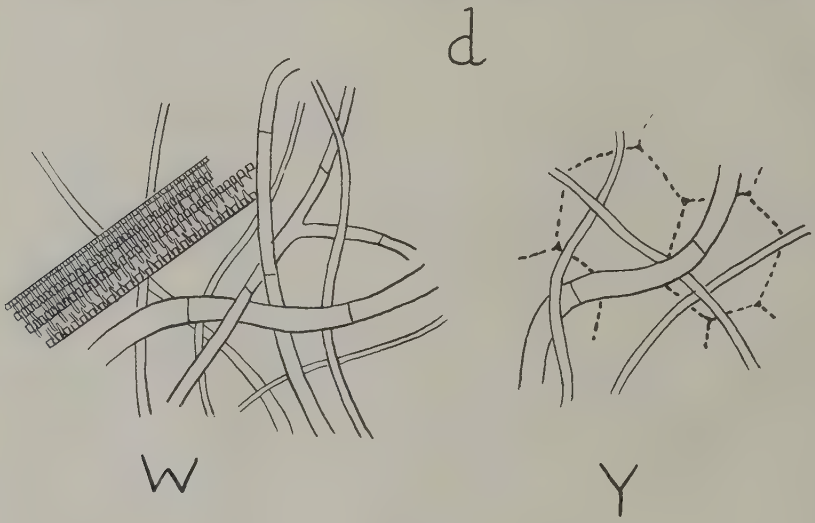

FIG. 6.

d. Part of the white rind (W) and the yellow rind (Y) from the region of old conidiophores. ×382 approx.

As far as the citrus *Penicillia* are concerned, there are indications that rotting is due to a system which may be enzymic and in which acid plays some part. The acid does not act by itself ; it functions rather as a necessary component of a single system. Hence, there can be no comparison with *Penicillium oxalicum*. It is obvious that much remains to be done to elucidate the stages of pectic decomposition of oranges by *Penicillium*, and to define the factors other than acid in the system responsible for the breaking down of rind resistance and for rotting.

V. CONCLUSIONS.

From the results of this investigation it seems possible to draw a partial picture of the infection of oranges by *Penicillium*, although much remains to be done before the picture can be considered complete. Infection is governed by two master factors:—

> (*a*) The degree of resistance of the rind which is inversely proportional to the degree of hydrolysis of the pectic cell walls. This resistance is always greatest in the outer layers of the yellow rind.
>
> (*b*) The degree of activity of the resistance-destroying system produced by *Penicillium* which brings about pectic decomposition. The system is present when the fungus grows on an orange, but it is not produced on synthetic media.

If *Penicillium* can attain the inner susceptible white rind it grows luxuriantly and the rotting involves the production of a very active resistance-destroying system. This enables the fungus to grow outwards through the resistant yellow rind to the exterior where conidiophores are formed. The ability of the fungus to attain the white rind in the first place determines whether the orange is to become rotten or not.

The various conditions which influence decay may all be classed as affecting either one or other of the above master factors. A deep wound penetrates the inner susceptible rind and is therefore usually infected readily, but minute wounds in the yellow rind are not infected unless the inoculum can produce a fairly active resistance-destroying system ; a still more active resistance-destroying system is required for infection through the uninjured rind. Hence, oranges which have been carefully picked and packed and are free from all but minute wounds are likely to remain sound indefinitely so long as infection depends on isolated casual spores of *Penicillium* on the rinds. However, given a very active resistance-destroying system in the shape of a recently rotted fruit, infection by contact through very minute wounds or through the uninjured rind is almost inevitable.

Ripe fruit is more susceptible to decay than unripe fruit. Carré and Horne (10) have already shown that ripening of oranges is associated with pectic hydrolysis, and hence in ripe fruit the pectic resistance is considerably decreased. Similarly, different varieties of oranges may show different degrees of pectic resistance, and thus varietal differences in susceptibility to decay are to be expected.

Dried out wounds are resistant to infection, even if they penetrate the white rind. By analogy with the nature of dried pectin, one would expect that the drying process would confer a resistance on the white rind in the shape of a hard horny lining to the wound, which is very resistant to decomposition by hyphæ.

External conditions such as temperature humidity and aeration not only have a direct effect on the orange itself but they also influence the activity of the fungus, and, in so doing, they may control the production of the resistance-destroying system which is generated in the rotting process. As regards the retarding action of alkalies and of certain volatile substances on infection, it is to be expected that they inhibit the growth of the spores or that, even if growth is possible, they inhibit the actual rotting process.

Partial though it is, the above conception of infection, as dependent on the degree of rind-resistance and degree of activity of the resistance-destroying system produced by the fungus, points to one or two important commercial aspects. It must be remembered that in my experiments the conditions to which the oranges were exposed were particularly severe. Under normal storage conditions in which the temperature and humidity are far from the optimum for rotting, sound fruit is likely to remain so indefinitely, provided there is no active resistance-destroying system present in the shape of a mouldy orange. However, given one mouldy orange, the infection of neighbouring fruit is almost inevitable. The first orange in the case to become mouldy represents the ultimate cause of all subsequent decay and the rotting of this orange must be carefully guarded against. It invariably becomes mouldy because of the presence of wounds through which casual spores may cause infection, and hence care in handling is still the most important method of preventing wastage. The presence of borax or bicarbonate may delay infection by contact, but cannot prevent it. Similarly, optimum storage conditions of temperature and humidity can only delay infection.

During picking there will probably be some unavoidable minute injuries made on the rind, and, although these are not usually susceptible to infection by casual spores, they may be rendered quite resistant by drying them. The commercial practice of keeping oranges in a drying atmosphere for a day or two before packing is thus to be encouraged.

The varietal differences in susceptibility have not been worked out, but they certainly exist. It may be possible to breed oranges with particular resistant outer rinds, but it may be difficult to combine pectic resistance of rind with good edible quality. In my experiments it was often noticed that oranges with thin rather translucent rinds seemed to be more readily infected than those with thick, rugged, opaque rinds ; unfortunately, the former are usually the best flavoured fruit.

VI. SUMMARY.

1. Previous investigations on the decay of oranges by *Penicillium italicum* and *Penicillium digitatum* have led to the view that infection depends on luxuriant growth of the inoculum, as determined by the available nutrient. This conception is shown to be wrong because luxuriant growth of the fungus does not necessarily bring about infection.

2. Minute shallow wounds in the form of pricks are not infected by an inoculum of spores in water. The depth of prick necessary for 100 per cent infection depends on the variety of the orange and the degree of ripeness.

3. Orange juice and rind promote infection through minute wounds, but synthetic media, in which *Penicillium italicum* grows very well and *Penicillium digitatum* grows fairly well, do not promote infection. Acids and ammonium oxalate promote infection, although these substances do not support the growth of *Penicillium* ; they act directly on the rind.

4. There must therefore be some resistance to infection in the outer rind which is broken down by acids and ammonium oxalate. By growth in orange juice or rind *Penicillium* yields a resistance-destroying system which is not produced by growth in synthetic media.

5. Provided that the resistance of the outer rind is overcome, infection can occur through the uninjured rind, the stomata being the channels of entry. Acids and ammonium oxalate induce infection. Juice and rind from a recently rotted orange, in which a very active resistance-destroying system is produced, enable infection of sound fruit to occur, and this finds its parallel in natural infection by contact. An old mouldy orange does not cause infection of sound fruit. Infection of the uninjured rind is also promoted by previous treatment of the fruit with chloroform.

6. The resistant outer rind is a hard compact tissue and contains no soluble pectin. The susceptible white rind is a soft tissue containing considerable quantities of soluble pectin. Wounds penetrating the white rind are usually readily infected but they may be rendered resistant by drying.

7. Acids and ammonium oxalate break down the resistance of the outer rind by hydrolyzing the insoluble pectic substances of the wall into pectin, thereby softening the walls and incidentally causing a decrease in cell turgor. Treatment with chloroform results in extreme autolytic changes, including loss of turgor and breakdown of semi-permeability. Changes due to autolysis are unlikely to occur under natural storage conditions.

8. *Penicillium* resembles acids in that it breaks down the rind-resistance by causing pectic decomposition, thus softening the walls, but, unlike acids, it carries the decomposition further and causes dissolution of the walls. It is

considered that the rind-resistance is mechanical in nature and that the direct cause of its breakdown by *Penicillium* and acids is softening of the walls. On the other hand, the breaking down of resistance by chloroform involves extreme autolytic changes.

9. Hydrogen-ion concentration is one factor in the resistance-destroying system produced by *Penicillium* in a mouldy orange. As the infecting power of mouldy rind decreases with age, its hydrogen-ion concentration also decreases. Hydrogen-ion concentration is not the only factor concerned. The other factor is unknown at present ; possibly it is enzymic.

10. Certain alkaline substances delay infection through deep wounds. With borax in particular, and to a lesser extent with sodium carbonate, the effects are greater than can be accounted for by hydroxyl-ion concentration alone, thereby indicating that other ions, such as the borate and carbonate ions, are important (compare Marloth (24)). For deep wounds and also for infection by contact these substances delay infection rather than prevent it.

11. Finally, it is concluded that there are two master factors governing infection of oranges by *Penicillium* and that all other conditions influencing decay are subservient to these. The master factors are :—

(*a*) The degree of pectic resistance in the outer rind.

(*b*) The activity of the resistance-destroying system which is produced by *Penicillium* on a mouldy orange but not in synthetic media.

This investigation was carried out at the Botany School, Cambridge. I should like to express my grateful thanks to Mr. F. T. Brooks, who supervised this work throughout, and to Dr. R. G. Tomkins, who has given me much helpful advice and criticism.

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(*Received* 8/9/32.)

BOOK REVIEWS.

HORTICULTURAL ABSTRACTS. Issued quarterly by the Imperial Bureau of Fruit Production, East Malling, Kent, England. 1s. 6d. per number, 5s. per volume of four numbers. First issued March, 1931.

The completion of the first volume of Horticultural Abstracts published by the Imperial Bureau of Fruit Production, East Malling, presents an opportunity for an appreciation of this publication. Its object is to provide full abstracts of important papers concerned with horticultural research in matters of fruit production and allied subjects. The completed Volume 1 provides a reference to 428 articles from 178 different publications, of which 103 are foreign, some 16 countries being represented.

The great value of this work is patent to all who have had access to it and the only similar work, "Botanical Abstracts," published in America, covered a much wider field. Those concerned in fruit production practical and scientific will be glad to have their special interest dealt with in one volume.

The abstracting has been well done and there are only one or two points upon which criticism might centre.

Firstly, there should be no ambiguity as to whether an opinion expressed is that of the author or the abstractor. Such phrases as "the figures given seem to substantiate" leave the reader in doubt on this point. It would, perhaps, be best that the author's opinion alone should find expression.

Secondly, the use of the word "type" in one article refers to a variety and in another to what would be known in botany as a form or sub-variety leads to confusion.

It would be well if Pomologists followed the botanists in using these terms. If a variety has a colour variation this should be known as a colour "form" if in all other respects identity is preserved. If it can be shown that there exist varieties differing in certain important characters, say earlier or more constant cropping, to these a new name should be applied. If the variation is of no cultural importance, such as a variation in leaf form, I suggest this should be known as a sub-variety.

Finally, it would be valuable to have the numbers of tests made in such work as cross-pollination and similar experiments where numbers only are convincing.

E.A.B.

FERTILIZERS AND FOOD PRODUCTION. By SIR FREDERICK KEEBLE, F.R.S. pp. 196+ix. Oxford University Press, 1932. 5s. net.

Sir Frederick Keeble's book deals with one of the most significant developments of modern science applied to agriculture.

The investigations of the first generation of scientific men concerned with agriculture, of Lawes and Gilbert in particular, were devoted to the study of the importance of nitrogen in the nutrition of the crop and of the sources from which the combined nitrogen in the world could be derived. The next generation recognized the part played by living organisms in the soil and showed that recuperative actions were at work to restore the ever wasting stock of combined nitrogen. Walforth cleared up the mystery that had surrounded the old-established fact of the fertilizing action of clover and similar crops, Beijerinck supplied an explanation of the accumulated fertility in virgin soils. Still nitrogen, the dominant element in fertility, remained dear, and in the newer countries supplying so much of the world's foods seemed to be undergoing rapid waste, so much so that Crookes in 1894 foretold the approach of scarcity unless some chemical or electrical method was contrived for bringing the nitrogen of the atmosphere into combination. Such processes were being slowly worked out, until the war came along and gave an extraordinary stimulus to invention. The Haber process was rapidly perfected, for without it Germany could not have continued the war. After the war national determination to be self-supporting as regards the raw material of explosives led to erection in many countries of factories for the fixation of nitrogen, and as there is little other outlet for these products in peace time except agriculture the farmers of the world suddenly found themselves endowed with supplies of nitrogen fertilizers amounting to about four times that which was previously being utilized. It cannot be said that they knew forthwith how to utilize this wealth, especially as the fall in agricultural prices was driving the farmer towards economy in every direction. But what the farmer, and indeed the world at large, needs is constructive economy, which may involve an actual increase of expenditure in one direction, provided it becomes the means whereby some other expenditure is rendered profitable. And that is what the new sources of nitrogen can do ; they can spread the most serious item of the farmer's expenditure—labour—over a greater amount of crop and so on balance reduce costs per unit. But some new technique is involved and it was to this end that Imperial Chemical Industries, with Sir Frederick Keeble as their adviser, established the experimental station at Jealott's Hill, from whence some of the results are set out in this volume. A lead in the new technique had been given by Warmbold at Hohenheim, who during the war had to keep a herd of cows going when both feeding stuffs and labour were reduced to a minimum. He found that grass land would respond to quantities of nitrogen hitherto undreamt of, provided the applications were repeated a little at a time and the grazing was regulated so that the grass was never allowed to pass beyond the young stage rich in proteins, which under ordinary practice only characterizes the first flush of late spring when the soil warms up and produces nitrates in abundance. Starting upon this basis, many of the investigations initiated by Sir Frederick deal with the adaptation of this principle to British conditions and with the exploration of the processes in the plant and the soil which lead to so remarkable an increase in production. The most immediately profitable outcome of the intensive use of fertilizers is the extension of the grazing season, beginning with the production of an " early bite " a month or so before grazing is normally available, followed by the maintenance of grass of high quality throughout the summer and far into the autumn, when under normal conditions grass might be abundant but had little feeding value. One of the most interesting results obtained at Jealott's Hill has been to show how sulphate of ammonia, applied early in the year when the average temperature is mostly below that which is required to induce growth, is yet absorbed by the grass and converted into some form that is immediately available for growth as the land warms up. The grass thus becomes active with every accession of seasonal temperature, it has not to wait until the warmth first starts the soil bacteria into activity whereby the reserves of nitrogen in the soil are changed into forms that can then be absorbed by the plant. Sir Frederick's book is thus very largely occupied by a discussion of the economic results that have been obtained upon grass land, but it is a plea for the increased use of fertilizers in all departments of farming, and as such will well repay the study of the fruit grower and market gardener. If fertilizers will produce a payable increase in the wheat crop, how much more valuable is a corresponding increase in fruit or vegetables! Some of Sir Frederick's considerations of the migrations of nitrogen within the plant and of its partition between plant, soil and bacteria, have their applications with regard to fruit trees. We yet know too little as to the most effective times of application of fertilizers, some of these results would suggest a much earlier date than is customary. Again the control of alternate fruiting in apples probably is to be sought through fertilizers. Those who know Sir Frederick are aware of his power of vivid and lucid presentation, this book is an example of his art of advising as he expounds without sacrifice of precision.

A. D. HALL.

ROOT STUDIES.

II.* THE ROOT DEVELOPMENT OF AN APPLE TREE IN A WET CLAY SOIL.

By W. S. ROGERS.

East Malling Research Station.

INTRODUCTION.

A remarkable case of an apple orchard in which the trees had made very good growth in spite of the fact that the soil appeared to be a practically waterlogged clay was found in the course of the Kent Fruit Soil Survey. As rushes were growing under the trees the location appeared to be one which would certainly not be recommended for fruit growing. It was therefore decided to make a study of the root behaviour of one of the trees under these conditions, and to try to discover why the trees were giving such a good performance. This was carried out by a root excavation in November 1930.

LOCATION AND MATERIAL.

The location of this orchard was at Boughton Malherbe, Kent, where the Hythe Beds plateau rises from the Weald clay, with a narrow strip of Atherfield clay between. The plateau forms a fairly steep escarpment of Ragstone rock, and at its base a line of springs is found where the water which percolates through the pervious Ragstone runs out on top of the underlying impervious clay.

The strip of orchards along the base of the escarpment has a downwash of loamy Hythe Beds material as top soil, overlying a subsoil of Atherfield clay material.

In this orchard the trees were three-quarter standard apples about 26 years old, on seedling apple roots. The orchard had been under grass and grazed by sheep for a number of years.

At the time of the excavation many patches of rush grass were growing under the trees, and the soil was very wet on the surface. In spite of this apparently most unfavourable soil condition, the trees were growing well and producing good crops.

Fig. 1 shows the tree selected for excavation. The variety is Bramley's Seedling apple. The growth of rushes can be seen in the foreground, and it can also be seen that the tree is still (November 1930) well covered with leaves, and certainly not unhealthy.

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* No. I of this series appears in the East Malling Research Station Ann. Rep. for 1926-27 (October 1928) (II Supplement), " The Root Systems of some ten year old apple trees on two different root stocks, and their relation to tree performance."

METHOD OF EXCAVATION.

Owing to the size and value of the tree, it was decided only to excavate a sector of the root system. This was carried out as follows:

The surface soil was dug away from the roots in a square extending one metre from the trunk (Fig. 2) and a sector which it was judged would include some representative roots was chosen. A trench was then sunk some distance from the tree, and the soil was worked away in blocks 50 cm. square and in four depths, 0–30 cm., 30–50 cm., 50–100 cm. and deeper than 100 cm. (100 cm. equals 3·28 feet, or about 39½ inches). The trench was widened step by step, until the last section reached the tree trunk as shown in Fig. 3. The roots were carefully uncovered, drawn on a plan, and then labelled, cut off, washed and, while just moist, weighed on a spring balance. For further information on technique of excavation see reference (1).

SOIL.

The nature of the soil is undoubtedly responsible for the tree and root performance in this case. Its full description (some details of which it was only possible to observe after the trench had become large enough to stand in) largely explains the root behaviour. A full examination of the soil was carried out by Mr. G. H. Jones, then soil surveyor at Wye College, who took a soil monolith in the trench and gave the following description of the profile at that spot.

"Top soil 20 cm. loam to fine sandy clay loam. Subsoil darkish brown loam to fine sandy clay loam with high proportion of organic matter and much fibrous root over a depth of 20 to 40 cm. Then light brownish clay loam with much yellow to rust mottling and much large pore space—the soil showing columnar structure, some black mottling and some vertical worm holes. This passes into a slightly heavier bluish grey to fawnish brown clay loam with 25 per cent rust mottling and some glauconite and black mottling, pronounced columnar structure and marked porosity (some small pores about ·2 mm. diameter and some much larger) with a few weathered ragstone stones, to about 150 cm. (about 5 ft.). This becomes still heavier (a silty clay) darker blue in colour with much less mottling, passing into a cinnamon brown and grey marbled clay at 200 cm. This continues to 250 cm. (about 8 ft. 3 in.) and then becomes a greyish-blue non-marbled clay, which is probably the pure underlying Atherfield clay, continuous to over 270 cm. (limit of observation)."

To the excavator the soil wall presented a thick and tenacious layer of turf, with many fibrous grass roots and tough rush roots extending into a blackish subsoil, which changed at 40 to 50 cm. to a stiff clay as described above. This

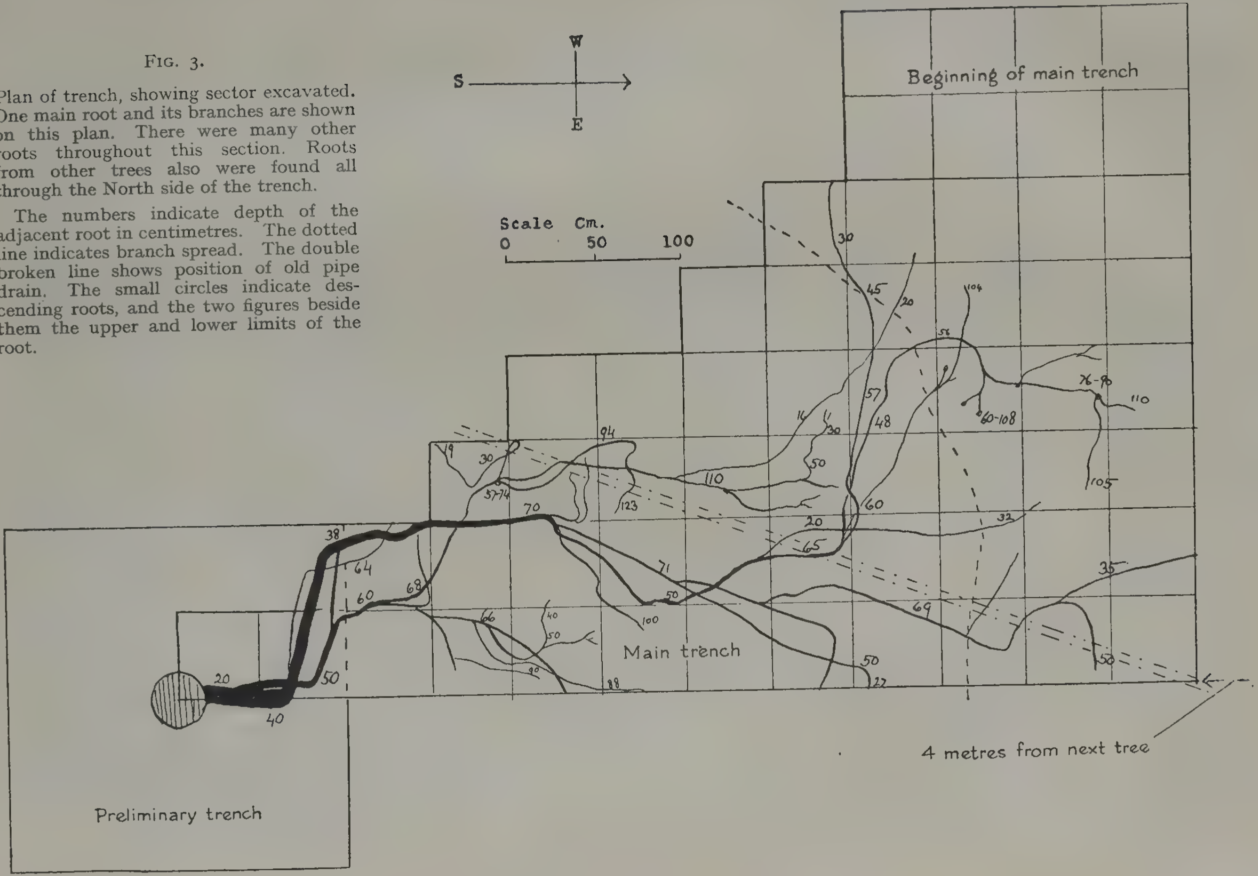
S
W
E
Scale Cm.
0
50
100
Beginning of main trench
Main trench
Preliminary trench
4 metres from next tree
30
45
20
104
56
57
48
76-96
110
60-108
105
14
11
30
50
60
110
94
19
30
57-74
70
123
20
65
32
38
64
60
68
71
50
100
69
35
58
66
40
50
90
88
50
22
20
40
50

FIG. 3.

Plan of trench, showing sector excavated. One main root and its branches are shown on this plan. There were many other roots throughout this section. Roots from other trees also were found all through the North side of the trench.

The numbers indicate depth of the adjacent root in centimetres. The dotted line indicates branch spread. The double broken line shows position of old pipe drain. The small circles indicate descending roots, and the two figures beside them the upper and lower limits of the root.

was very sticky and tenacious, and every inch had to be hacked away. There was no falling down of the soil when gently prodded with a fork, as occurs in light loams or sands. Digging out the roots from the clay with the small hand fork was almost like cutting them out of cheese or soap. An old army entrenching tool proved a useful implement for the coarser work.

Branch Measurements.

The tree chosen for excavation was about 6 metres high, and had a mean spread of 9·2 metres. Its girth at 15 cm. from the ground was 91·5 cm.

The Tree Roots.

On digging away the soil round the tree trunk to a depth of 40 cm. one or two fairly shallow roots were found, but the majority of the roots were seen to be striking steeply downwards, as shown in Fig. 2.

When the main excavation trench was dug out, starting at a distance of 6 metres from the trunk, very few roots were found in the top layer of soil (0 to 30 cm.). As the trench was dug nearer the tree, a number of fairly small roots, often with very fibrous ends, were found rising upwards from the second section into the first, as shown in Fig. 4. The second depth section (30 to 50 cm.) usually disclosed a few more roots, but even here they were mostly fairly small, and not very numerous, as shown in Fig. 5. This photograph also shows the general appearance of the trench as it approached the tree. In the background can be seen the rough stand which served as a table for the root plan and record sheets, and as a support for the spring balances.

The third depth section (50 to 100 cm.) contained more roots, which were mostly running horizontally at a depth of 55 to 70 cm. These roots branched and sent small laterals in all directions, including upwards and downwards. These roots were not very large, usually less than 1 cm. in diameter at distances greater than 2 metres from the trunk. It appeared likely, therefore, that the real main roots of the tree were going straight down below the trunk.

This question was answered when the excavation trench reached the centre of the tree, showing the centre roots as seen in Fig. 6. It can be seen that the big main roots, although descending so steeply at first, curve round to the horizontal position at a depth of 90 cm. or less. They also taper and divide up very rapidly.

There were a number of roots of a diameter of 2 cm. or less descending vertically below the trunk. These turned sharply into the horizontal position at a depth of 90 cm. as shown in Fig. 6. A few small roots continued downwards to a depth of over 100 cm. The deepest roots found reached a depth of 127 cm.

The general depth of root is also shown by the figures for root weight in the different layers. As only a sector comprising about one-tenth of the soil within range of the tree roots was excavated, no reliable figures for total root can be obtained. The relative depth can be judged, however. In the following table the weights of roots in the centre block extending a metre from the trunk are omitted, as they were not all cut off. This table is therefore not comparable with the root depth tables in reference (1).

TABLE I.

Depth of Rooting of 26-year old Bramley's Seedling.

Depth.	Percentage of total root weight in layer indicated.
0–30 cm.	12·8
30–50 cm.	21·3
50–100 cm.	63·5
Below 100 cm.	2·4

This refers only to the sector excavated. The total root weight in this sector was 7,779 gm. The block extending 1 metre from the trunk is excluded from these figures.

Table I shows how in the region beyond 1 metre from the trunk, 63·5 per cent of the root weight was between 50 and 100 cm. deep. Only 12·8 per cent was above a depth of 30 cm., and 2·4 per cent was below 100 cm. It is clear that in this case the region between 50 and 100 cm. (or about 18 inches to 3 feet) is where most of the roots are.

This can be correlated with the soil conditions as follows :

SOIL MOISTURE, AERATION AND TEXTURE.

Moisture determinations made in the trench in duplicate on November 14th gave the following figures :

Depth.	Moisture, per cent of dry soil. (Mean of two determinations.)
0–30 cm.	43·6
30–50 cm.	27·3
50–100 cm.	23·6

Other determinations made on November 7th and December 1st gave closely similar results.

The very wet top soil, combined with the effect of the grass and rush roots, appears to have kept most of the apple roots out of that region.

The clay below, as already noted, contained many minute pore spaces, and had a columnar structure. Thus, although it was very tough it tended to come away in rough squares, or flat sided lumps, between which were distinct cleavage lines. This is illustrated in Fig. 7. The cleavage lines can be seen and also the sticky nature of the clay (shown by the pick marks at the left and the bottom of the photograph). The lighter roots are apple roots, and the black roots rush roots. The rush roots went straight down without branching to a depth of 100 cm. and over.

Free water oozed out of the soil at a number of spots in the trench at 90 to 100 cm. deep. Water collected in the hole below the centre of the tree shown in Fig. 6, and its depth below ground level was measured from time to time by Mr. W. A. Bane, of East Malling Research Station, with the results given below.

Date 1930.		Level cm.
December	2nd	119
,,	12th	94
,,	23rd	92
1931.		
January	1st	94
,,	21st	94
February	11th	94
March	13th	96
April	14th	96
,,	30th	94
June	4th	97
,,	25th	97
July	31st	95
September	26th	98

It thus appears that there was a region between 50 and 90 cm. deep where there was a better balance of moisture and aeration than above or below it. This conclusion is strengthened by results of some determinations of air space in the soil which were made by Mr. Jones on a soil monolith taken in the trench. These showed a much higher percentage of the soil volume to be occupied by solid matter and water at about 90 to 100 cm. deep, and a lower percentage to be occupied by air at this depth than nearer the surface.

A possible explanation of the formation of the well aerated and porous region of clay is suggested by the slope of the orchard. The free water appeared to be constantly moving down the hill, and doubtless this helped in the drawing in of air and the avoiding of stagnant conditions.

The depth distribution of the roots as already described, and the sharp turning of the vertical roots at 90 cm. below the tree trunk, show that the roots evidently would not tolerate constant immersion in water. The fact that living roots were found to a depth of 127 cm., however, shows that they could live very near to and even just below the top limit of the moving water table. The information on the soil air condition is limited, but such observations as were made are highly suggestive that it was not excess of water but deficiency of aeration that has been the controlling factor in root depth.

One further interesting find was an old 2-inch pipe drain which ran across the trench, at a depth of 115 to 120 cm. as shown in Fig. 3. Its existence was quite unknown to the owner of the orchard or to any of the workmen, and it was judged to have been put in at least 30 years before. It was found to be running at the time of the excavation, and its influence in drying the soil was evident for a short distance around it, though free water oozed from the soil at a spot 50 cm. away from it and 20 cm. above it.

Where the soil was drier it cracked up into flat sided lumps much more readily but offered more resistance to the pick.

DEAD ROOTS.

A few dead ends were found on living roots at depths of 63 to 90 cm. At one spot a curious " sour " smell similar to that in another excavation in clay soil at Wisboro' Green, Sussex, was noted. The exact nature of this gas has not yet been determined.

ROOT SPREAD.

The trench at a width of 6 metres reached the ends of nearly but not quite all the roots in that sector. It also included many roots from the next tree which was 10 metres away. No full root plan is given, but one main root is shown on the trench plan in Fig. 3 showing how the root follows a tortuous course in clay soil. The branch spread is also marked. It can be seen that the roots extend farther than the branches.

The Grass and Rush Roots.

The grass roots extended well into the subsoil, but not many were noted in the clay (50 cm. deep). They were no doubt responsible for the large amount of organic matter in the subsoil, and possibly helped to form the pores in the clay below. These roots were white and very fine.

The rush roots, as already noted, grew straight downwards without branching, and many reached depths greater than 100 cm. These roots had a dark brown or black skin, which appeared to be loose and flabby. Thus the root only partly occupied the hole it had made, which probably allowed freer drainage of water from above.

The rush roots were so tough that only a strong blow with a spade or pick could sever a tuft of rushes from the soil. The rushes were mainly *Juncus effusus* L.

ACKNOWLEDGMENTS.

This work was carried out with the financial assistance of the Ministry of Agriculture in connection with the Kent Fruit Soil Survey undertaken jointly by the South-Eastern Agricultural College, Wye, and East Malling Research Station.

The author expresses his thanks to the Soil Survey Committee for their permission to publish this special investigation as a separate study ; and also to J. Kitchin, Esq., owner of the orchard, for his permission to excavate the tree used. He acknowledges with thanks assistance received from the Soil Survey workers, notably Mr. W. A. Bane, of East Malling, and Mr. G. H. Jones, who was then at Wye College.

The author also thanks the authorities of the Dominion Experimental Station, Summerland, B.C., for placing their office facilities at his disposal for the preparation of this report during his stay in British Columbia.

SUMMARY.

1. A section of the root system of a 26-year old Bramley's Seedling apple on seedling stock was excavated from a wet clay soil in a grass orchard.

2. Although appearing to descend steeply from the trunk, the main roots were found to curve round to a horizontal position at a depth of less than 90 cm. (about 3 ft.).

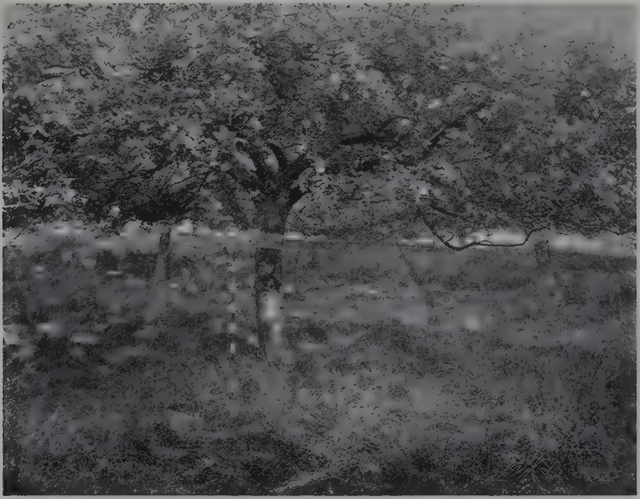

FIG. 1.

Bramley's Seedling apple tree selected for root excavation. Note rushes in foreground.

The measure is marked in tenths of a metre. 1 metre = 3·28 ft.

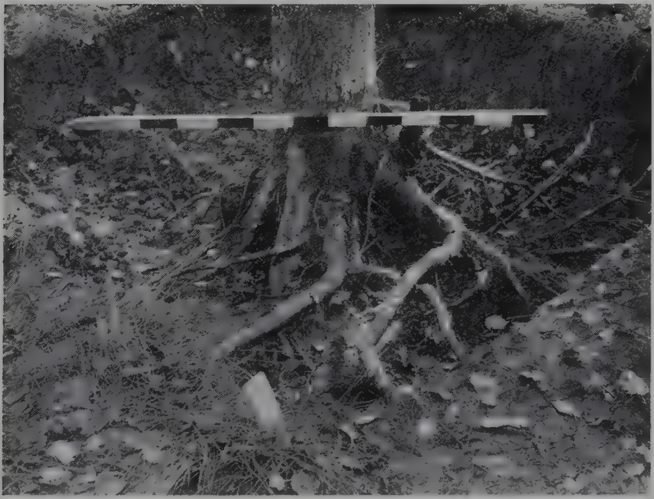

FIG. 2.

Preliminary uncovering of centre roots, showing steeply descending main roots. The measure is fixed at ground level. It is marked in tenths of a metre.

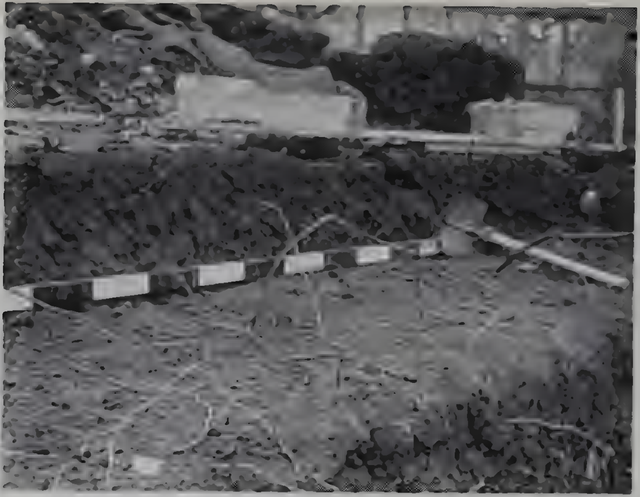

Fig. 4.
First layer of soil removed, showing tree roots rising from second layer.

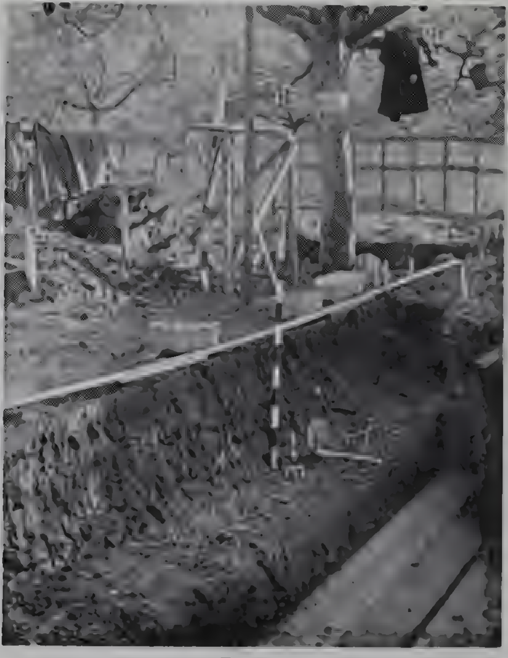

Fig. 5.
Face of trench with second layer of soil removed. Some small horizontal roots are seen, and others rising from layer 3.

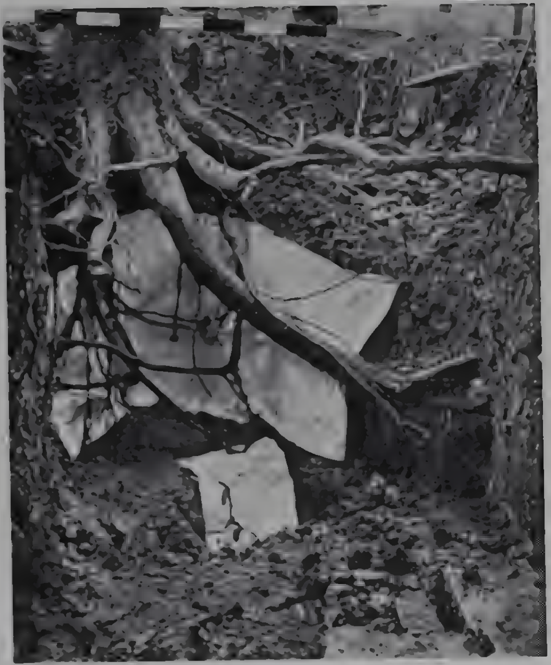

FIG. 6.

Roots at centre of tree. Note the vertical roots turn horizontally at 90 cm., and the large main roots also turn to a horizontal direction. Water collected just at the bottom of the large sheet of paper.

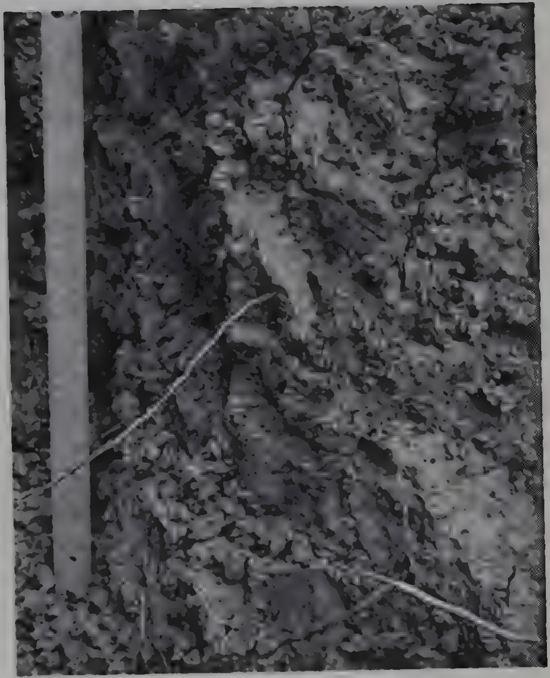

FIG. 7.

The clay in which most of the roots were growing. Note the columnar structure and cleavage lines. The light roots are apple and the black vertically descending roots are rush roots. The measure is marked in in. and cm.

3. The bulk of the roots grew in the stiff clay between 50 and 90 cm. deep. Branch roots extended upwards to just below the grass, and downwards to a maximum depth of 127 cm.

4. Free water was found at a depth of 90 to 100 cm. The top soil was also very wet, and rushes were growing in the grass. It appears that the region of soil between 50 and 100 cm. had a balance of moisture and aeration more suited to the roots than either the top soil or the soil below 100 cm. Although there was abundant free water, stagnant conditions were apparently prevented by the slope of the orchard.

5. The roots spread farther than the branches. A certain amount of root interlacing was found although the trees were 37 feet apart.

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(*Received* 14/6/32.)

THE LEAF RELATIONS OF FRUIT TREES.

I. A MORPHOLOGICAL ANALYSIS OF THE DISTRIBUTION OF LEAF SURFACE ON TWO NINE-YEAR OLD APPLE TREES (LAXTON SUPERB).

By M. C. VYVYAN and H. EVANS,*
East Malling Research Station.

I. Review of Previous Work on Leaf Relations.

The influence of rootstock, pruning, cultural treatments and other factors, upon the stem characters and the fruiting performance of fruit trees has received more attention than their influence on the leaf relations, though it is probable that these factors bring about their characteristic effects on stem and fruit, in part, through their influence on the leaves.

The importance of the leaf, however, has by no means been overlooked. As early as 1897, the pioneers Bedford and Pickering (2) tried to estimate the effect of various cultural treatments by measurements of leaves. These authors were so impressed by the importance of leaf measurements that they state (3), " For annual measurements of the vigour of trees we have relied on the size or weight of the leaves " and that " The size of the tree may be taken as a record of the past history . . . whereas the size of the leaf is a measure of the vigour of the tree at the time being." They were interested in the leaf mainly, however, as a convenient index of the vigour of the tree. A considerable number of papers on leaf relations has been published since that date.

Great practical difficulties are involved, however, when the foliage on a tree is to be measured. Not only are the leaves far more numerous than the stems that bear them, but they are individually more troublesome to measure. The work, moreover, has to be crowded into a short period during the growing season, and cannot be spread over the ensuing dormant period, as with wood measurements.

In reviewing previous work on leaf relations, it will be convenient to examine, first the methods various workers have adopted to meet these practical difficulties, and then to examine the results they have obtained.

The methods used for the actual measurement of the size of individual leaves will not be reviewed here, as it is proposed to make this the subject of a separate paper dealing fully with the technique of leaf measurement. The areas were usually either determined with a planimeter, or estimated from measurements made of the length and breadth of the leaves.

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* Dr. Evans carried out this work during a six months stay at East Malling prior to taking up his duties as Plant Physiologist to the Sugar Research Station, Mauritius.

A. *Methods Used in Previous Work.*

The methods adopted by different workers have varied with the scope and aim of their investigations. Some workers have sought to determine the response of a whole tree, or of a large branch system, to an experimental treatment, others have limited themselves to the leaf relations of some particular types of growth, such as the leader shoots, or the bearing or non-bearing spurs.

In investigations of the first type, no attempt seems to have been made to measure every leaf on a tree—except in the case of very young trees. Ellenwood (10), using Gerdel and Salter's (12) photo-electric cell method, did actually measure the size of every leaf on some large apple branches, but even here the investigation was confined to representative branches bearing some 2,500 to 3,000 leaves. Estimations of the response of the tree or branch have usually been based on measurements made on a relatively small proportion of their leaves, and the methods used for the selection of these leaves have varied.

Some investigators have used leaves situated at strictly similar positions on each tree or branch. Thus Bedford and Pickering (2) (3), when comparing trees grown under different experimental conditions, took the sixth leaf from the apex of each of six shoots situated at about equal intervals round the circumference of each tree, and determined their areas or weights. In some cases they combined these measurements with counts of the total number of leaves on their trees and attempted, thereby, to determine the total leaf surface or weight on each. Mann (22) for a similar purpose determined the areas of the ten youngest leaves on all the shoots of his experimental trees. Howlett (17) and Gourley and Howlett (14), when comparing ringed and unringed branches and trees, relied on the areas of the fifth to ninth leaves—counted from the base—of the terminal current year's shoot on each branch.

While these authors seem to have relied mainly on identity in the position of the leaves to render their measurements comparable, others have sought to determine the true mean size of the leaf on their different trees or branches, by measuring representative samples.

Gourley (13) based his estimate of the mean size of the leaf upon 100 leaves per tree, five being taken from each of twenty representative " twigs ". He does not state his method for selecting the " twigs " or which leaves on each were chosen.

Austin (1), in his work on apricot trees, counted the leaves on each tree three times in the course of the year and, on each occasion, measured a sample of 100 leaves per tree to determine the mean areas. He counted the leaves on growth from spurs, shoots from one year wood and growths from old wood separately, and found that the relative numbers on these three types of growth varied with the time of year and with the experimental treatment, but he does not describe what precautions he took to ensure that leaves from each type were represented in their correct proportions in the samples used for determinations of leaf area.

Haller and Magness (15) and Magness (20) estimated the mean size of the leaf, on branches undergoing different experimental treatments, by measuring 100 leaves from trees of each variety. They do not mention their method for ensuring that the samples should be truly representative, nor do they state if they found local changes in the values of the mean area brought about within branches as a result of the differential treatments. In a more recent paper, however, on the same general lines, Magness, Overley and Luce (21) give the mean area of the leaf on branches under each treatment.

Chandler (7) and Chandler and Heinicke (9) describe in full their methods for rendering their samples representative. In the case of peach trees (7), " sample sets of leaves from different branches were taken at intervals outward. More leaves were taken from branches whose leaves showed especially great variation in size. The number of leaves to the sample varied from twenty to sixty, and there were three samples to the tree." In the case of cherry (7) and apple (7, 9) trees, " spur " leaves and " twig " leaves were counted and sampled separately on account of the great differences between them. No distinction seems to have been made between " bearing " spurs and " non-bearing ". From two to four samples of " spur " leaves and as many of " twig " leaves were taken from each tree on each occasion.

Where the investigation has been confined to the leaf relations of growths of some particular type, such as the leader shoots or the " bearing " and " non-bearing " spurs, it has been usual to measure every leaf on the growth concerned. But even here, only a sample of growths of the particular type has been taken from the general population on the tree.

Thus Wiggans (30), in his work on the leaf relation of " bearing " and " non-bearing " spurs, took, in 1915, a number of spurs " large enough to be representative of the tree as a whole ", and, in 1916 and 1917, based his data on more than 250 spurs. Roberts (25) does not state the number of spurs upon which he based his observations.

Harley (16) required his material for chemical analysis, as well as for determinations of leaf area. He therefore found it necessary to select spurs of exactly uniform length. His samples, on that account, cannot be regarded as representative of the general population on his trees. Both Kraybill and his collaborators (18) and Potter and his collaborators (24) based their measurements on samples of forty spurs from each experimental treatment. Swarbrick (27) confined his observations to " several medium-sized branches " but measured all the leaves on every spur on these.

In their recent paper on the effect of rootstock on leaf area and internode length, Swarbrick and Naik (28) confined their attention to long shoots and measured about thirty on each tree. They grouped the shoots according to the number of leaves they bore, but for convenience in analysis only used those groups which contained the largest proportion of the total number of shoots.

The difficulties involved in the presence of enormous numbers of leaves on the trees have thus been met in one of two ways. Either the investigation has been limited to growths of some particular type, such as the long shoots or the bearing and non-bearing spurs, or else an estimate of the mean leaf size on the tree as a whole has been based upon a relatively small sample of the leaves.

Sampling methods are, of course, thoroughly legitimate, and an obvious method of dealing with difficulties of this kind, but unfortunately many of the investigations were carried out before the necessity for using strictly random samples, and for ensuring that the variability within a sample reflected that of the general population, was fully realized. Samples were, therefore, frequently selected so as to be composed of " typical " leaves, or leaves from " typical positions ". In the hands of a skilled observer, such a sample might give the mean area of the leaf on a tree with greater accuracy than a random sample of the same number of leaves, but the variability in the size of the leaf on a tree cannot be determined from it, nor can the significance of a difference in the mean areas on two trees be established, when the variability within the samples has been reduced artificially in this manner. In the hands of a less skilled observer, moreover, there is a chance of an unconscious personal factor biassing the results.

B. *Principal Results of Previous Investigations.*

Although the methods used by different workers have varied and their results possibly on that account are sometimes conflicting, the general result of previous investigations shows that the leaf relations of a fruit tree can be considerably altered by a number of different internal or external factors.

Bedford and Pickering (4) have shown that many cultural practices of a kind that, in general, may be called " neglect " resulted in a decrease in the size of the leaves, though the reduction in leaf size was often less than that in stem growth. For example, careless planting, and the growth of weeds, caused marked reduction in size.

The same authors found some reduction in leaf size resulted when trees were left completely unmanured. Omission, however, of one of the three main constituents, potash, phosphate and nitrate, had little effect on leaf size at Woburn.

Mann (22), on the other hand, found at Long Ashton that deficiency in potassium caused considerable reduction, whilst deficiency in calcium resulted in a great increase, in leaf area.

Kraybill and his collaborators (18) found that the leaf surface per spur was considerably less in apples grown under " sod " and receiving no fertilizer, than in those on a cultivated plot receiving fertilizer rich in nitrogen. They do not state, however, whether this difference in area was due to there being fewer leaves per spur, or to the leaves being individually smaller.

Many authors have investigated the effect of pruning on leaf relations. Bedford and Pickering (4) found that the size of the leaf on an apple tree was decreased for a year or two if the trees were not cut back at the time of planting nor subsequently pruned. Summer pruning also sometimes reduced leaf size.

Austin (1) has compared the leaf relation of apricot trees subjected to two types of pruning ; he measured his trees three times in the year. He found that trees which had been severely cut back, as well as thinned, had smaller leaves throughout the year than those which had been thinned only. The number of their leaves was likewise less in April, but in May and October was greater. The distribution of leaves between growths from spurs, shoots from one year wood, and growths—mainly water sprouts—from old wood, was profoundly altered by the severity of pruning.

Chandler (7) does not give mean leaf areas for his trees but expresses his results as total leaf surface. He mentions, however, that the twig leaves on some pruned peach trees were larger than those on unpruned controls, though the total leaf surface was greater on the latter. He has shown that the degree and type of pruning may greatly influence the total amount of leaf surface developed on an apple tree and its distribution between spurs and twigs and between upper and lower branches. Severe pruning usually reduced leaf surface.

Chandler and Heinicke have also shown that pruning tends to reduce leaf surface in the vine (8) and the apple (9).

The effect of blossoming and of fruiting on leaf relations has been investigated by many authors. Gourley (13) found that the mean area of the leaf on an apple tree was smaller in the bearing than in the non-bearing year, whilst Howlett (17) and Gourley and Howlett (14) found that, when a branch of an apple tree, ringed the previous season, bore a heavy crop of fruit, it tended to have smaller leaves than an unringed branch that was not bearing a crop. They remark that the reduction in leaf size was no greater than normally met with on heavily cropping branches. In each case the leaves measured seem to have been " twig " leaves and not to have included those from spurs.

Chandler and Heinicke have tried the effect of deblossoming on the leaf relations of the vine (8) and the apple (9). Their investigation extended over several years. In the vine deblossoming seems to have had no very marked effect, but in the apple the leaf area of the deblossomed trees began to gain on the controls in later years when the latter had begun to bear heavy crops.

Whilst these authors have been concerned with the tree or branch as a whole, others have concentrated upon the leaf relations of particular types of growth, such as bearing and non-bearing spurs.

Harley (16), in the course of his investigation on the chemical composition of bearing and non-bearing spurs, determined the leaf area and leaf number on each type of growth. He found the leaf area on the non-bearing spurs about double that on spurs bearing blossoms. His spurs, however, were selected so as to be of exactly uniform length, and his bearing spurs each bore one secondary growth. The leaf area included that on this secondary growth, as well as that on the primary " bourse ".

Kraybill and his collaborators (18) record similar results. Whether their trees were grown on " sod " or " nitrate " plots, the leaf surface was greater on the non-bearing spurs than on those bearing blossoms. Here again the values for the bearing spurs seem to have included the leaf area on secondary growths arising from them.

Swarbrick (27) examined two biennially bearing apple trees one of which was in crop in 1925, and the other in 1926. The majority of the spurs bore blossom in the " on " year whilst none bore any in the " off " year. He found that the mean size of the leaf on a spur was greater in the year when the spur was in a vegetative state, than in the year when it bore blossom. The total leaf area on the spur was, moreover, far greater in the " off " year, even when that borne by secondary growths was included in the value for the " on " year. Spurs that were vegetative in the " on " year of the tree had larger leaves and a greater leaf surface than " bearing " spurs. In the year when a tree bore no fruit, however, these spurs, which were vegetative both seasons, bore larger leaves than they did in the year when the tree bore a crop. It would seem, therefore, that blossoming, or fruiting, decreased the mean area not only in the actual bearing spurs but even in vegetative spurs on the same branch.

The effect of fruiting, as distinct from blossoming, on the size of leaves on a spur, has been investigated by Roberts (25). He found that early blossoming did not increase the size of the leaves on the primary wood or " bourse " of the fruiting spur, but did increase the number, and to some extent the size of those on secondary growths borne on that structure.

Similar results have been found by Potter and his collaborators (24). Complete deblossoming of every spur on a tree resulted in an increase in leaf area on the secondaries which grew out rapidly from the spur. When, however, only the alternate spurs were deblossomed and the others were left to fruit, the presence of fruit on the latter checked the growth on the deblossomed spurs. This provides further evidence that the presence of fruit on one spur may affect the growth of other spurs on the same branch.

In this connection it is of interest to note that Haller and Magness (15) and Magness (20) report that a fruit can draw material from a leaf situated some considerable distance from the point where it is borne. These authors, however, were concerned with the influence of leaf surface upon fruit growth rather than the converse. By suitable thinning of leaves and of fruit on ringed branches of apple trees, they were able to show that there was " a strong correlation between leaf area and the increase in volume of the fruit . . . up to a certain point beyond which a further increase in the number of leaves did not result in a corresponding increase in volume ". In a fuller investigation (21) on the same lines, Magness, Overley and Luce have confirmed these findings for the apple and have found that they hold good also for the pear. Ellenwood (10) did not find so close a relation between the amount of leaf surface and the volume of the fruit, but he was using unringed branches.

Very recently, Swarbrick and Naik (28) have shown that the leaf relations of shoots can be influenced by the rootstock. While the number of leaves per shoot was not widely different on different stocks, there were marked differences in the mean lengths of the internodes and in the distribution of long and short internodes along the shoot. The mean size of the leaf also was affected by the rootstock, it was least on very vigorous stocks such as Malling No. XII and B.5, largest on the less vigorous Malling No. I, whilst it was intermediate in size on the very dwarfing Malling No. IX. Owing to differences in mean internode length on the various stocks, the leaf area per unit length of stem was found to be directly related to the vigour of the stocks. Within each stock, there was a close correlation between the size of a leaf and the length of the internode below it.

Roberts (25) has shown that the mean length of the internode in a " non-bearing " spur is influenced by the total length of the growth. He says, " As the length of the spurs increases from near zero to one-half an inch, the number of leaves and especially the leaf area is greatly increased. . . . As the spurs become longer than a half-inch, or those having about eight leaves, the amount of leaf area in relation to the length is greatly reduced because of longer internodes nearer the terminal end."

II. AIM AND SCOPE OF PRESENT INVESTIGATION.

The investigations summarized in the preceding section have shown that :

(1) The leaf relations of a tree or branch system as a whole may vary considerably with the fruiting condition of the tree and with the treatment it has received.

(2) The leaf relation of different types of growth, such as the non-bearing and the bearing spurs, may be very dissimilar and may respond differently to changes in conditions.

(3) The relative numbers of these different types of growth may vary from tree to tree and from season to season on the same tree.

The investigations have not shown clearly how changes in the mean size of the leaf and of the total leaf surface on a tree are brought about. Whether they are due to an all round increase in the size of the leaves throughout the tree, or whether they are due to localized changes in area confined to particular types of growth, or to a mere change in the relative proportions of small-leaved and large-leaved types of growth.

To investigate this problem it would be necessary to determine the mean size and the mean number of the leaves on each type of growth and to record the numbers of growths that belonged to each category.

This could be done by determining the size and position of every leaf on the trees. It could also be done by sampling separately from each type of growth.

No investigator seems to have attempted to measure every leaf on any except very young trees, though counts have sometimes been made. Where sampling has been resorted to, no attempt has been made to sample from each type of growth separately, or at the most, " spurs " and " twigs " have been kept separate.

The number of leaves that would have to be measured would be so large, even if sampling from each type of growth was resorted to, that an investigation of this kind would probably be impracticable, with the slow and troublesome methods of leaf measurement at present in use.

Work on the technique of leaf measurement has been in progress for some years at East Malling with a view to evolving a quick and accurate method of estimations of area in the field so as to reduce the practical difficulties mentioned above. As a result of this work a method has been evolved which seems to offer considerable advantages over those in common use ; this method will be described in full.

The investigation described in this paper was designed partly to test this method, by applying it to the measurement of all the leaves on two mature trees, and partly to collect data on the magnitude of the variation, in the number and size of leaves, on growths of different types, that might serve as a basis for the elaboration of a sampling method.

The trees chosen for measurement were of the same variety, but were on different stocks and in different fruiting condition. Analysis of the data has revealed interesting points of difference between types of growth and trees. These form the subject of this paper.

No details of sampling methods based on the data will be given in this paper as they have not yet been fully tested out on other trees in the field. But the values for the co-efficients of variability in leaf numbers and leaf sizes, upon which sampling methods can be based, will be given on pages 256 and 257.

III. METHOD OF LEAF MEASUREMENT.

Only the actual method used in this particular investigation will be described here. The leaves were measured in the orchard, without detaching them from the tree, by a special device which for convenience may be termed an " integrator ". The essential part of this device consisted of a sheet of glass accurately divided into squares of one centimetre by two sets of ruled lines crossing one another at right angles. The complete instrument is illustrated in Figs. 1 and 2. It consisted of two sheets of glass attached respectively to the upper and lower lips of a " bull-dog " spring clip ; the upper sheet was the actual integrator, the lower sheet, covered with white paper to provide a good background, was the surface against which the leaf was gripped for the purpose of measurement. The integrator sheet was mounted so that the ruled side should be underneath and in contact with the leaf. When in use, the two levers of the clip were held between finger and thumb ; by pressing the levers together the jaws of the clip were opened and the two sheets of glass thereby moved apart. The jaws were then allowed to close in such a way as to grip the leaf between the two sheets of glass. The area of the leaf was estimated by counting the number of squares in the portion of the integrator in immediate contact with the surface of the leaf. The region round the margin of the leaf frequently occupies some fractions of squares. In the preliminary tests, every fraction that was greater than half a square was counted as a whole square, whilst fractions that were less than half were neglected. It was found possible, however, after some practice, to balance the fractions of contiguous squares into complete squares, and as a result the estimation of the leaf areas was made more accurate. This latter method was followed in the work here described. It is often possible to eliminate the fractions of squares to a large extent by gripping the leaf so that its longest piece of straight margin coincides with one of the lines ruled on the integrator.

The variety used in this investigation, Laxton Superb, is especially suitable on account of the normal flatness of its leaves.

Occasional curled leaves occurred on the trees but they were comparatively rare. There are two methods of dealing with such leaves ; their true areas may be estimated more or less accurately by determining the areas of the folded portions, which usually show up rather darker than the rest of the leaf against the white background, or the convention may be followed of taking the apparent area, i.e. the vertical projection of the leaf. The latter alternative was followed in this investigation.

It might be thought that increased accuracy could be obtained by dividing the " integrator " into smaller squares. The " integrators " used in some preliminary tests were in fact divided into squares of one-quarter centimetre each.

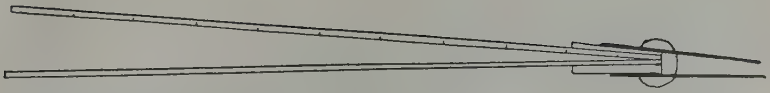
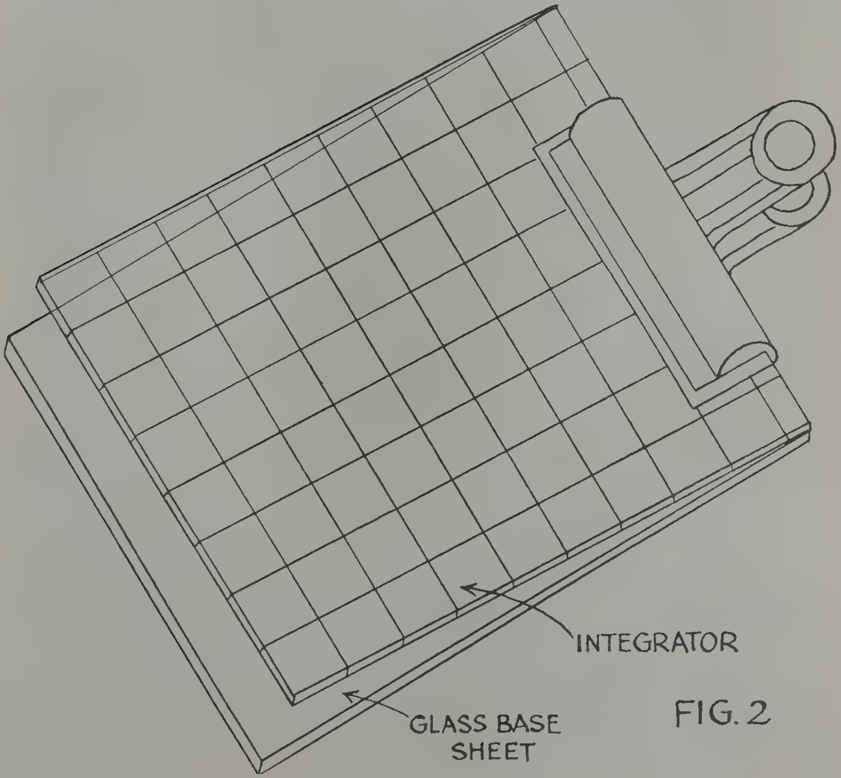


FIG. 1. SECTION (Open)



INTEGRATOR
GLASS BASE SHEET

FIG. 2

The lines, ruled half a centimetre apart, were made alternately thick and thin, so that the thick lines divided the plate into squares of one centimetre whilst the thin lines subdivided these into quarters. In the main portion of the leaf only the larger squares had to be counted, but in the regions where the margin of the leaf crossed a square, the smaller squares were used. Comparative tests, however, showed that the gain in accuracy, so obtained, was too small to justify the considerable decrease in speed of determination.

The speed of recording is greatly increased if two workers co-operate, one doing the measurements, the other entering up the results. The tedium is greatly reduced if these two workers exchange at intervals their respective tasks. Such an exchange, however, introduces another possible source of error—the " personal factor " of the observer. To determine the magnitude of the errors inherent in the method various tests were carried out. For example, every leaf on two shoots, of one of the trees, was measured twice by each investigator ; the shoots each bore sixteen leaves, making thirty-two in all. The outline of each leaf was then traced and its area determined by means of a planimeter. The accuracy of the values found with the integrator was tested by the X^2 method.* Each of the four series of integrator values, determined two by each investigator, was in turn compared with the single series of planimeter values. The four values thus found for X^2 were 1·81, 3·49, 2·16 and 2·76 respectively. For the differences between integrator values and planimeter values to be significant, the value for X^2 would have to be about 45·0, since the number of observations was thirty-two. It is clear, therefore, that neither the integrator method, nor the personal factors of the two investigators, introduced serious errors into the determination of the leaf areas.

IV. MATERIAL USED AND MEASUREMENTS TAKEN.

A. *Material Used.*

The material used in the investigation consisted of two nine-year-old apple trees, of the variety Laxton Superb, worked respectively on the Malling rootstocks Nos. IX and V. No. IX is a rootstock which produces a comparatively dwarf tree that comes early into bearing, while No. V produces a more vigorous tree which is later in coming into cropping. A photograph of the two trees, taken at the end of the investigation, is reproduced in Fig. 3. Both trees showed the typical characteristics associated with their respective rootstocks. The tree on No. IX, however, had been showing marked biennial bearing for some years and was in its " on " year at the time of the investigation, whilst that on No. V had never yet produced a heavy crop and bore only a light one at the time of the investigation.

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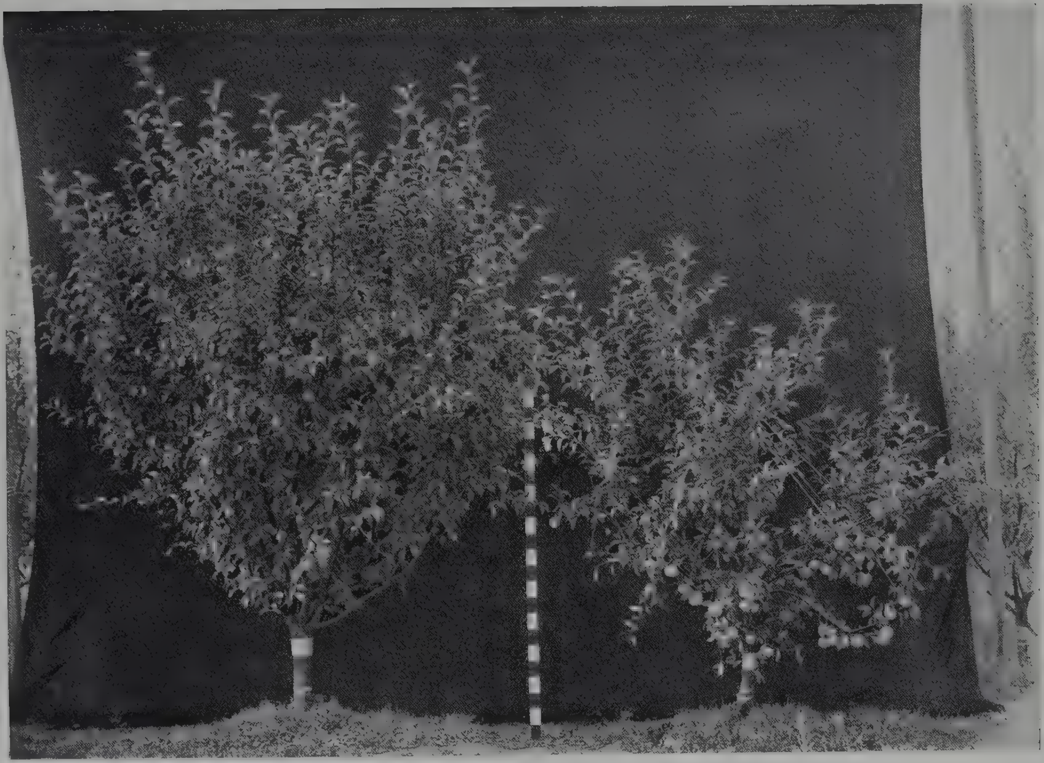
* The statistical methods used in this paper are those described by Fisher (11).



On No. V. On No. IX.

FIG. 3.

Photograph of the two trees of Laxton Superb used in the investigations.

For the purpose of the investigation, which was in the main to determine the magnitude of differences to be expected between trees, and of the variation in the character of leaf relations between and within growths of different types, these trees were very suitable.

The trees had received the same cultural and pruning treatment throughout their lives and their fruit had not been thinned. Annual measurements of wood growth (i.e. lengths of shoots formed each year) had not been taken, but the length of the surviving wood of each year's growth was measured in the course of the investigation and is given in Table I. These values do not represent the actual lengths of wood formed in the respective years. They are the summed lengths of all shoots and spurs of each year's growth that were still present and alive in the summer of 1931 when the investigation was carried out, having survived all past pruning operations and accidents. Though they do not give an exact measure of the growth that took place each year, they do provide a striking picture of the relative sizes of the two trees at the time of the investigation.

It was not found practicable to measure the lengths of wood formed in seasons previous to 1925. That formed in 1924, when the trees were two years old, was made up of the short forks at the base of the main branches ; whilst the 1923 wood was represented by the actual trunks of the trees.

Table I.

Summed Lengths of Surviving Wood of each Year's Growth.

	G.	F.	E.	D.	C.	B.
Year ..	1925.	1926.	1927.	1928.	1929.	1930.
Age ..	3	4	5	6	7	8
On IX	237	875	600	1168	1812	1451 cm.
On V ..	232	1005	896	2209	3591	3096 cm.

The differences between the trees, in the amount and character of this wood of past years, will be examined in greater detail in a later section (page 262).

B. *Measurements Taken.*

Commencing at the tip of the current year's growth nearest the apex of a main branch, the area of each successive leaf was determined until the base of that growth was reached. Where a leaf had fallen or was too badly damaged to measure, this fact was recorded. The length of the growth was then determined to the nearest half centimetre and, in the case of long shoots, a paint mark was made at the tenth node from the apex, so that the respective nodes could be identified after the leaves had fallen. On the completion of the growth, similar measurements were made on any secondary growths arising from it.

Working downwards from the apex, each current year's growth in turn was recorded in a similar manner, until the base of the 1930 growth bearing them was reached; the length of this growth was then recorded.

The same procedure was followed until the base of the main branch was reached; thus the size and position of every leaf and the length of the stem of every growth, whatever its year of origin, was determined. Each branch in turn was measured in the same manner.

It was found convenient to employ a simple terminology to describe the position of the various growths and their years of origin.

Growths formed during the current year (1931) were denoted by the letter "A"; those formed during the previous year by the letter "B". The letters "C", "D", "E", "F" and "G" were in the same way used to denote growths formed in 1929, 1928, 1927, 1926 and 1925 respectively.

The "A" growths, derived from buds borne on any individual "B" growth were serially numbered from the apex, and the same system of numbering was followed in the case of the growths of previous years. Where a growth was derived from a terminal bud, it was denoted by the symbol "O"; the growth from the most apical axillary bud being given the number "1". Buds that had failed to grow out received their appropriate numbers even if only represented by leaf scars, so that the serial number given to a growth represented its real position on the growth of the previous year. Where a growth had been broken or pruned, the most apical surviving bud was denoted "1", though the true position relative to the original apex was not known. The fact that the growth had been pruned or broken was recorded. Secondary growths were called "A Axil", "B Axil" etc. according to the year of their origin. Each leaf and growth on the tree had thus its own notation and subsequently could be easily located on the tree.

In addition to these records of leaf size and stem length, records were also made of the numbers and positions of all blossom scars, aborted fruit and fruit.

The records were taken towards the end of the summer when the shoots had ceased to elongate and the leaves had reached their final size.

V. PRESENTATION AND ANALYSIS OF RESULTS.

A. *Morphological Analysis of Current Year's Growths.**

1. *General Scheme of the Analysis.*

The morphological analysis will be carried out in successive steps, the first of which can be conveniently represented by the following schema. The numbers in brackets refer to the subsections concerned.

---

* The term "growth" is used in this paper in a general sense, to include all types of spurs and shoots, whatever their origin or character. It may be defined as an organ derived from the activity of the growing point of a single stem.

Schema.

- (2) Whole tree
  - (3)
    - Primary Growths
      - (4)
        - Spurs
          - (5)
            - Bearing
            - Non-bearing
        - Shoots
    - Secondary Growths
      - (6)
        - from " Bourses "
        - from " Shoots "

In subsection 2 each tree will be considered as a whole and the total numbers of growths and of leaves borne on each compared. The values for the mean lengths of the stem, the mean number of leaves per growth and the mean area of the leaf will also be given and compared.

In subsection 3 the growths will be separated into those of primary and those of secondary origin. The former being those derived from dormant buds laid down on wood of the previous year, the latter those derived from buds borne in the axils of leaves on current year's growths.

In subsection 4 the primary shoots will be divided into spurs, or short growths, and shoots or long growths. For reasons that will be given the actual basis for the division will be leaf number and not stem length.

In subsection 5 the primary spurs will be further subdivided into " bearing " and " non-bearing " spurs. By a " bearing " spur will be meant one derived from a " fruit " bud of the previous year whose terminal bud has therefore been used up in the formation of a blossom bud. All such growths will be included under the term " bearing " whether or not they were actually bearing fruit. By a " non-bearing " spur will be meant one derived from a " leaf " bud of the previous year ; whose terminal growing point was still present and capable of further vegetative growth, though it had not grown out into a shoot. In subsection 6 the different types of secondary shoots on the two trees will be compared.

Having sorted out the various types of growth into categories according to their origin, character of growth and performance, the leaf relations within the categories will then be compared in two subsections not shown in the above schema. In 7 the relation between the number of leaves on a growth, the mean length of its stem and the mean area of its leaf will be examined. In 8 the relation between the size of a leaf and its position on the stem will be analysed.

The results of the morphological analysis will be summarized in three further subsections. In 9 the co-efficients of variability in leaf number and leaf size in different categories of growths will be given. In 10 an attempt will be made to estimate the total leaf surface developed by each tree. Finally in 11 the relative effects of different morphological factors influencing total leaf surface will be compared.

2. *The Tree as a Whole.*

The main morphological characteristics of the two trees are compared in Table II. The values given include all the growths on the trees, whether primary or secondary, spurs or shoots, bearing or non-bearing.

The total number of growths on each tree, their summed lengths and the total number of leaves they bore, are given in the upper part of the table. As some of the leaves on each tree were either too badly damaged to measure or had already fallen, the number of those actually measured is given also.

The mean values for the length of stem, the number of leaves per growth and for the area of the leaf are given in the lower half of the table. The values for the mean internode length and for the mean leaf area per centimetre of stem, which are given at the base of the Table, were obtained by dividing the mean length of stem by the mean number of leaves, and by dividing the mean area of the leaf by the value of the mean internode length so obtained.

TABLE II.

Comparison of the Leaf Relations of the Two Whole Trees.

	IX.	V.
Total Number of 1931 Growths	1,468	2,053
Summed Length of 1931 Stems in cm.	9,128	29,416
Total Number of Leaves	10,435	20,006
Number of Leaves Measured	9,156	17,978
Total Area of Measured Leaves in sq. cm.	117,008	318,232
Mean Length of 1931 stem in cm.	6·08	14·33
Mean Number of Leaves per Growth	7·11	9·74
Standard Error	**·127**	**·176**
Mean Area of Leaf in sq. cm...	12·78	17·70
Standard Error	**·075**	**·069**
Mean Internode Length in cm.	·855	1·476
Mean Leaf Area per cm. Stem	14·96	11·99

It is evident that the two trees differed widely in every respect. The tree on No. V had about 40 per cent more growths than the tree on No. IX and nearly twice as many leaves. Its stems on an average were more than twice as long and bore a significantly larger number of leaves.

The mean area of the leaf was about 40 per cent greater and the difference in mean area is significant. Owing, however, to the much greater average internode length on the No. V, the value for the leaf area per unit length of stem was greater on the No. IX.

3. *Primary and Secondary Growths.*

Growths may be either primary or secondary in origin. Primary growths are those derived directly from buds laid down in the previous season. These buds, which may be either terminal or axillary in position, have remained dormant from the time they were formed until the ensuing spring, when they have burst into renewed activity. Secondary growths, on the other hand, are derived from buds formed in the axils of leaves on current year's growth ; they represent buds that have developed into leafy growths in the year of their origin instead of waiting until the succeeding spring.

Some secondary shoots may arise as a result of accidents, they may grow out from near the apex of primary shoots whose terminal growing point has been damaged or killed.

In the apple, however, numerous secondary growths often arise as a normal outcome of the summer activity. In primary growths derived from " fruit " buds, the terminal growing point has been used up in the formation of a blossom bud. Such a growth may lengthen the internodes already laid down and may thicken its stem to form that typical structure known variously as the " bourse " or the " cluster base ", but it cannot grow out into a primary shoot of indefinite length by the formation of new leaves and internodes. It is normal for such structures to develop two, occasionally three, secondary growths in the axils of leaves below those subtending fruit, and these secondaries may grow out into shoots of considerable length.

In addition to those " bourse " secondaries, others are frequently formed, in the normal course of events, in axils of leaves on primary shoots. A growth of this type is often limited to the formation of a single leaf but sometimes it attains a considerable length and bears several leaves. Similar growths may arise from the axils of leaves on shoots that are themselves secondary ; such growths are, of course, tertiary in origin.

In Table II no distinction was made between primary and secondary growths. Thus a primary " bourse " bearing two secondary growths was counted as three growths and not as one, though the whole structure was represented as a single dormant bud during the previous winter. Vinson (29) cites cases where these laterals, borne on a " bourse ", may have been laid down the previous season as dormant buds within the primary dormant bud, but in this paper all such laterals will be grouped with the secondaries.

There is considerable evidence, however, in favour of regarding the primaries and secondaries as distinct categories of growths. Roberts (26) points out that " the secondary growth may make growth responses which are markedly independent of the cluster-base ". He suggests, it is true, that " the functioning of the secondary growth is very similar to a vegetative spur of similar length and diameter " but numerous observers have pointed out that fruit buds are formed more rarely on secondary than on primary growths. Potter and Kraybill (23) suggested in 1925 that " the actual chemical environment of the terminal buds on secondary shoots of the bearing spurs was not the same as that of the terminal buds on non-bearing spurs ", and Lagasse (19) has provided chemical evidence supporting this suggestion.

The morphology of the two types of growth, moreover, is different, as Boyes (5) has pointed out. Primary growths have their basal leaves closely clustered together, whilst in secondary growths the base internodes are relatively long. It will be shown in this paper that there are other morphological differences between the two types of growth.

In view of these considerations, the growths of primary and secondary origin have been separated as a first step in the morphological analysis of the shoot systems of the two trees.

The results of thus separating the two types of growth are summarized in Table III.

TABLE III.

Leaf Relations of Primary and Secondary Growths.

	Primary.		Secondary.	
	IX.	V.	IX.	V.
Number of Growths	789	1847	679	206
Mean Length of Stem	4·36	15·41	8·37	4·57
Mean number of Leaves	6·47	10·21	7·85	5·54
Standard Error	**·163**	**·190**	**·196**	**·301**
Mean Area of Leaf	10·70	17·91	14·48	14·46
Standard Error	**·112**	**·072**	**·095**	**·205**
Mean Internode Length	·675	1·508	1·066	·842
Mean Leaf Area per cm. Stem	15·86	11·87	13·58	17·17

The relative numbers of primary and secondary growths were very different in the two trees. On the No. IX the secondaries were almost as numerous as the primaries, but on the No. V they formed only a small proportion of the total number of growths.

In the case of the primary growths, the differences between the trees are in the same direction as in Table II, but larger and more significant.

In the case of the secondary growths, however, the relation between the two trees has been largely reversed ; that on No. V proving to have shorter stems and internodes, fewer leaves per growth but a larger leaf area per unit length of stem. The mean area of the leaf on the secondaries was almost identical on both trees.

The effect of including the secondaries with the primaries in Table II, was to mask, rather than to accentuate, the differences between the two trees.

The great differences in the sizes of the leaves on the primary growths of the two trees, and the close similarity in size on the secondaries is clearly shown in Figs. 4 and 5.

In Fig. 4 are plotted the actual frequencies of leaves of each size on the four groups of shoots: Primary on IX, primary on V, secondary on IX, and secondary on V. In Fig. 5 are shown the relative frequencies, obtained by dividing the actual frequencies by the total number of leaves in each group.

In the case of the primary growths, the relative frequencies are widely different in the two trees, and the curves definitely skew in form. In the case of the secondaries, however, the two curves more or less coincide and are of a symmetrical form.

4. *Primary Spurs and Shoots.*

The next step in the morphological analysis was to separate primary growths into spurs and shoots. For it is conceivable that differences, such as those revealed by Table III, might be brought about by a difference in the relative proportions of these two types of growth on the two trees; provided that the size of leaf and the length of internode was different on spurs and shoots.

Before separating the growths into these two categories, it was necessary to decide exactly what should be deemed to constitute the one or the other type of growth. The existence of these two types is very obvious on the tree and is accepted by all workers, but occasional intermediate types of growth occur. As Bradford (6) points out, " distinction between spur and shoot is at times difficult, as it is occasionally between tree and shrub, though in either case the terms carry rather definite and well-understood meanings."

It is usual to take some arbitrary length of growth as the point of demarcation, and to regard all of less than that length as spurs. In wood measurements at East Malling, the standard used is 5·0 cm., in the U.S.A. 3 inches or 76 mm. is often taken as the point of demarcation. As the standard only comes into play in the exceptional cases of growths of intermediate type, its exact value probably makes little difference to the proportion of growths assigned to one class or to the other.

Although it is usual to adopt a certain length of stem as the standard, Bradford points out that " there is . . . some reason to believe that the number of leaves may be fully as accurate a criterion as length growth ". The results of this investigation are in complete accord with this statement.

When examining the relation between the length of a growth and the number of leaves it bore, two alternative courses were possible. The growths could be classified according to their length and the mean number of leaves on those of each length determined, or they could be classified according to their number of leaves and the mean stem length for each leaf number determined.

In this investigation, the current year growths were measured to the nearest half centimetre, and varied in length from less than ·25 cm., to well over 100·0 cm. If the first alternative had been followed the number of classes would therefore have been prohibitive unless " grouping " had been resorted to, and marked asymmetry in distribution made that unjustifiable.

The largest number of leaves borne by any growth was only thirty-five, the second alternative was therefore followed as being more convenient, and the growths classified according to the number of their leaves.

The frequency distribution of leaves between growths of different leaf number are shown in Figs. 6 and 7. The values in Fig. 6 refer to all the growths on each tree, they include those of secondary as well as those of primary origin. The values in Fig. 7 refer to the primary growths alone. Being frequency distributions, these figures should theoretically be presented as histograms, but for greater clearness the tops of the columns have been represented as points and have been joined by lines to simulate curves.

In each figure the growths have been classified along the base line according to the number of leaves they bore, while the total number of leaves (borne on growths of each class) has been indicated by the height of the curve above the appropriate point on the base line. The height thus represents the product of the number of growths of a given leaf number and the leaf number itself.

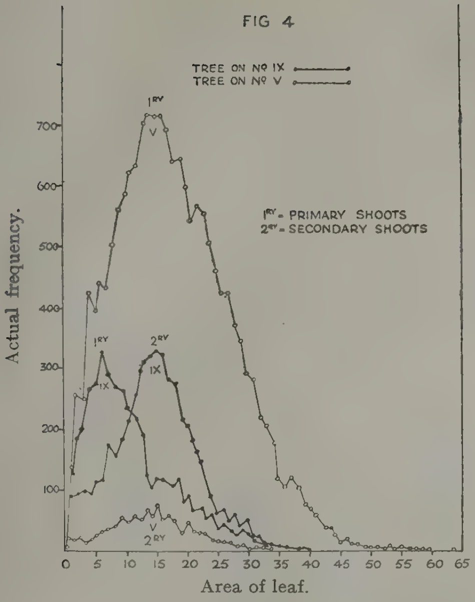
In both figures, it will be seen that the curves are obviously of a compound nature, made up of two portions which correspond more or less with the " spurs " and the " shoots " of pomological nomenclature.

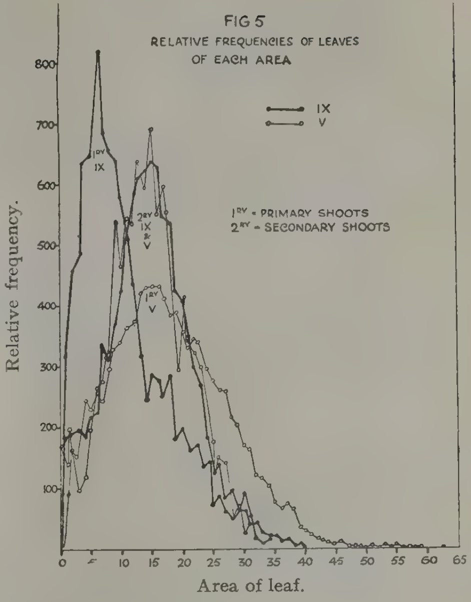
Whilst each portion, in itself, shows an approximation to the normal frequency distribution, the compound curves are widely removed from that type ; the mean values falling as they clearly do near the minima between the two maxima ; their actual position depending partly on the relative magnitudes of the two portions of the curves and partly on the positions of the maxima.

The portions of the curves corresponding to spurs, or rather to growths of low leaf number, are not very dissimilar in the two trees, but the portions corresponding to shoots are very unlike. The tree on No. V had a far larger number of leaves borne on the growths of high leaf number.

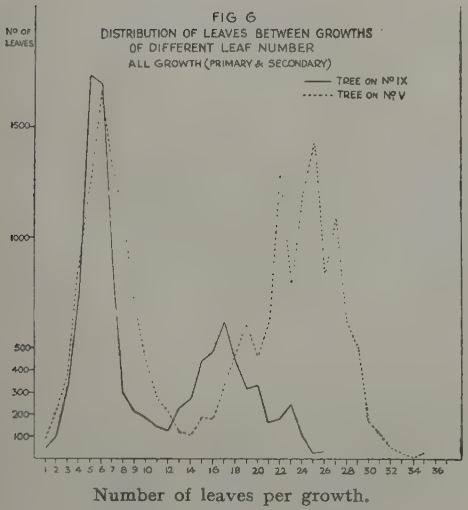
It is convenient to draw the line of demarcation between growths with ten leaves and those with eleven ; calling all growths with ten or fewer leaves "spurs" and those with eleven or more leaves " shoots ".

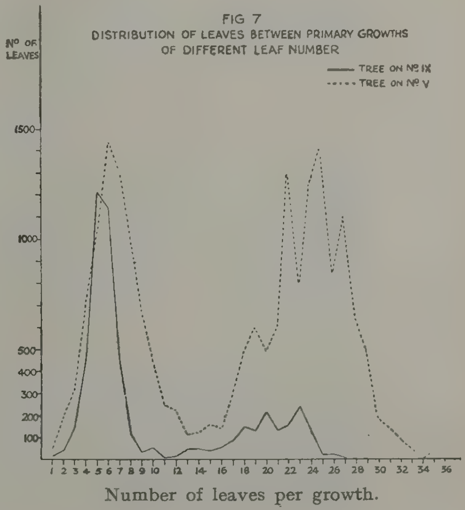
It is of interest to compare the result of this grouping, on the basis of leaf number, with that obtained by the more usual method of grouping on the basis of stem length. In the case of the primary growths on No. IX, the results are surprisingly close. Out of 714 growths with one to ten leaves, only two had lengths of more than 4·5 cm. whilst only one of the seventy-five growths bearing eleven or more leaves had a length of less than 5·0 cm. In the tree on No. V





Actual and relative frequencies of leaves of each area.





the approximation was not quite so close. Of the 1,313 primary growths with one to ten leaves, eight had lengths of more than 4·5 cm. whilst twenty of the growths bearing eleven or more leaves had lengths of less than 5·0 cm.

In view of these facts, it seems quite justifiable to group the primary growths into " spurs " and " shoots " on the basis of their number of leaves, including in the former group all those with one to ten leaves, and in the latter group those with eleven or more leaves. The result of grouping the growths in this manner is shown in Table IV.

TABLE IV.

Leaf Relations of Primary Spurs and Shoots.

	Spurs (1-10 leaves).		Shoots (11 or more leaves).	
	IX.	V.	IX.	V.
Number of Growths	714	1,313	75	534
Mean Length of Stem	1·12	·81	35·23	40·74
Mean Number of Leaves	5·10	5·45	19·57	21·93
Standard Error	**·0536**	**·0613**	**·381**	**·191**
Mean Area of Leaf	7·49	15·61	16·96	19·28
Standard Error	**·1063**	**·1258**	**·195**	**·085**
Mean Internode Length	·220	·149	1·801	2·339
Mean Leaf Area per cm. Stem	33·99	83·03	9·42	8·24

It is clear from Table IV that the explanation offered above to a large extent holds good. The relative numbers of growths in the two groups, bearing one to ten and eleven or more leaves respectively, are very different in the two trees, and the values for the mean length of growth, mean number of leaves per growth and mean internode length are very different in the two groups of growths. But within each group the values for these characteristics are of somewhat the same order of magnitude in each tree. The suggested explanation breaks down, however, in the case of the mean area of the leaf on growths with one to ten leaves ; the difference between the trees with respect to this character is the greatest yet found, the mean area for the leaf on No. V being more than twice that for the leaf on No. IX. In the case of leaf area per unit length of stem the position of the trees has been reversed, that on No. V having now very much the higher value.

5. *Bearing and Non-bearing Spurs.**

The relative numbers of bearing and non-bearing spurs were very different on the two trees. If the mean area of the leaf was not the same in spurs of the two types, this difference in their relative numbers might be a sufficient explanation of the widely divergent values found when the spurs were all grouped together. The bearing and non-bearing spurs have therefore been separated and the values so obtained are summarized in Table V.

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* By a " bearing " spur is meant one that has had its terminal growing point " used up " in the formation of a blossom.

TABLE V.

Primary Growth with one to ten Leaves.

	Bearing growths.		Non-bearing growths.	
	IX.	V.	IX.	V.
Number of Growths	586	130	128	1183
Mean Length	1·28	1·30	·38	·76
Mean Number of Leaves	5·28	5·78	4·23	5·41
Standard Error	·0459	·0966	·1964	·0671
Mean Area of Leaf	7·04	8·49	9·35	16·17
Standard Error	·0752	·1690	·3104	·1323
Mean Internode Length	·243	·225	·090	·140
Mean Leaf Area per cm.	28·95	37·69	103·72	115·20

The difference in the relative numbers of bearing and non-bearing spurs on the two trees is very striking ; more than four-fifths of the spurs on the No. IX had borne blossoms whilst nine-tenths of those on the No. V had remained purely vegetative. There were no great differences between the two trees with respect to the leaf relations of the bearing spurs ; the tree on No. V had slightly larger leaves and shorter internodes, resulting in a considerably greater mean area of leaf surface per unit length of stem. In the case of the non-bearing spurs, however, there is still a very wide difference between the values for the mean leaf area on the two trees. A suggestion as to the possible explanation of this difference will be offered in the discussion at the end of this paper.

6. *Different Types of Secondary Growth.*

Secondary growths are not all alike in their mode of origin, and the relative numbers of the various types were not the same in the two trees. The vast majority of these growths arose from axils of leaves borne on the " bourses " of bearing spurs whose terminal buds had been used up in the formation of blossoms. The great disparity in the relative numbers of secondaries on the two trees was therefore probably a mere reflection of the great differences in the relative numbers of this type of spur. In addition to these " bourse " secondaries, however, there were others that had arisen from the axils of leaves on shoots. The tree on No. IX had also a few growths of the third order, arising from axils of leaves borne on " bourse " secondaries. Although the mean area of the leaf was rather widely different in the " bourse " and the " shoot " secondaries, within each class it was of about the same order of magnitude in each tree. It is not worth while to present a full summary of the leaf relations on these different types of shoot, but the mean area of the leaf on the " bourse " secondaries was 14·52 sq. cm. and 14·75 respectively on the No. IX and the No. V whilst the corresponding values for " shoot " axillaries were 8·00 and 10·73.

7. *Growths with Different Numbers of Leaves.*

Having grouped the growths into classes according to their origin and character, it is now possible within each class to examine the relation between the number of leaves on a growth and its other leaf and stem characteristics. The values for the mean area of the leaf in the two trees are plotted in Figs. 8, 9 and 10 which refer to the primary non-bearing, primary bearing, and the " bourse " secondaries respectively. Where the values are significantly different in the two trees, this is indicated by the letter " S " placed between them. The values for the mean stem lengths on the non-bearing primaries and the " bourse " secondaries are plotted in Figs. 11 and 12 respectively. In non-bearing primary growths the values for mean leaf area are consistently higher in the tree on No. V, up to shoots of eighteen leaves, and in those of low leaf number, corresponding to vegetative spurs, the differences are significant. Significant differences occur also for shoots of fourteen, twenty-four and twenty-five leaves, but the number of shoots in those groups was low on No. IX, and there are consequently great fluctuations in the mean areas ; the size of the differences in area in these cases is probably due to the fluctuations in the two trees happening to be in different directions. The mean area is also usually higher on No. V in the case of bearing spurs, and in three groups it is significantly higher. On " bourse " secondaries the mean leaf area is consistently higher up to growths with eight leaves, on growths of higher leaf number there is clearly no consistent difference between the two trees. The mean stem length of the primary non-bearing growths is consistently greater on No. V but that of the " bourse " secondaries is clearly of much the same value on both trees. On both trees the mean stem lengths of the " bourse " secondaries were also consistently shorter than those of non-bearing primaries of the same leaf number, whilst the corresponding values of the leaf areas on the two classes of growths were of somewhat the same order of magnitude.

8. *Relation of Leaf Size to Position on Shoot.*

There was great variability in the size of the leaves on both trees. This is clearly seen in Figs. 4 and 5, and is proved by the values for the co-efficients of variability in leaf size which are given in Table VIII. The values are especially high in the case of non-bearing spurs and shoots and in secondary growths.

This variability is due in part to the differences in the mean area of the leaf on growths of different leaf number, but the co-efficients of variability within

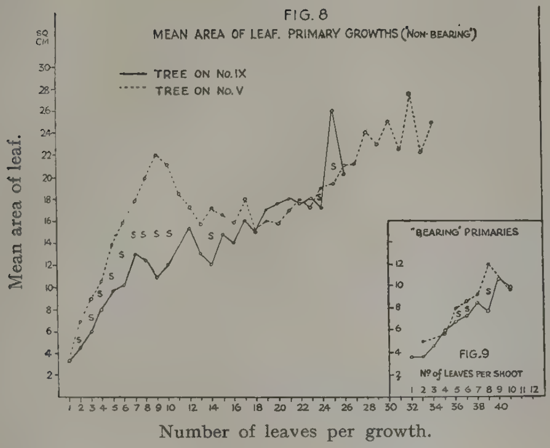


FIG. 8
MEAN AREA OF LEAF. PRIMARY GROWTHS ("NON-BEARING")

"BEARING" PRIMARIES
FIG. 9

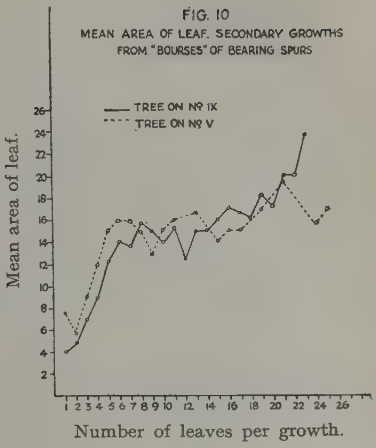


FIG. 10
MEAN AREA OF LEAF. SECONDARY GROWTHS FROM "BOURSES" OF BEARING SPURS

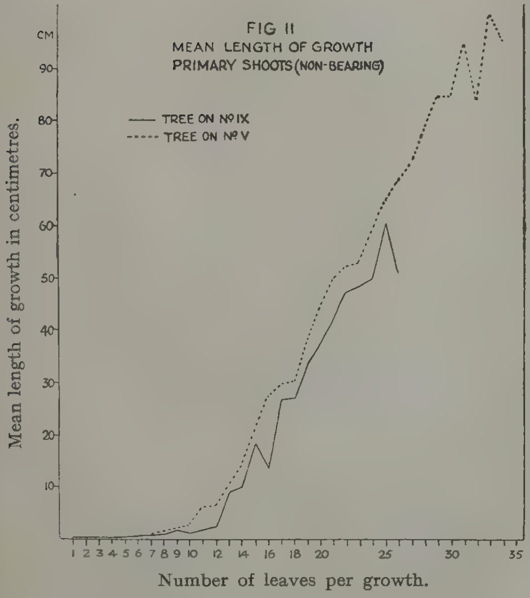


FIG 11
MEAN LENGTH OF GROWTH PRIMARY SHOOTS (NON-BEARING)

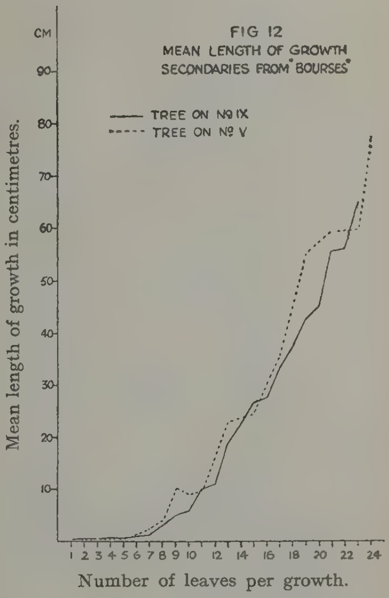


FIG 12
MEAN LENGTH OF GROWTH SECONDARIES FROM "BOURSES"

groups of growths all bearing the same number of leaves were often very high also, so this cannot be the sole cause. The variability must be due in part to differences between the mean values for growths of the same leaf number and in part to variation in the size of the leaf borne on individual growths. The variation within a growth might be fortuitous and bear no relation to the position of the leaf on the stem or there might be a definite correlation between leaf position and leaf size. The latter would seem to be an important source of variation as there is an obvious progressive change in leaf size proceeding from the apex to the base of the longer shoots—though the nature of the change is not the same in every variety. The proportion of the variation due to each of these factors might be determined by an analysis of variance, but in most cases this procedure was not justifiable, as many shoots of each leaf number had leaves that could not be measured, and the number and position of these leaves was not the same in each case. On the tree on No. V, however, twenty of the fifty-nine primary shoots bearing twenty-two leaves each were complete with every leaf measured; these, therefore, have been used in an analysis of variance. The mean area for the 440 leaves borne on these twenty shoots was 18·38—a close approximation to 18·09, the value for the whole group of fifty-nine shoots. The total sum of the squares of the deviations of the areas of the individual leaves from the general mean was 28,601·6. Of this, 5,384·1 was found to be associated with the shoot; this portion was due, that is to say, to the deviations of the mean leaf areas of individual shoots from the general mean. To determine the portion associated with the position of the leaf on the shoot, the leaves were numbered serially 1, 2, 3 etc. from the apex to the base on each shoot, and the mean area of the leaf at each position determined. It had frequently happened, especially near the base and the apex, that two or more leaves had arisen so close to one another on the shoot that it was impossible to determine which was the more apical. In such cases the leaves were bracketed together in the original records. In determining the mean leaf area at each leaf position, the areas of leaves so bracketed were summed and their combined area apportioned equally between the leaf positions concerned. The sum of the squares of the deviations, of the mean areas at the twenty-two leaf positions, from the general mean was found to be 12,489·9. Deducting this value and that due to the deviations between shoots from the

TABLE VI.

Variance due to	Degrees Freedom.	Sum Squares.	Mean Squares.	Half Loge. Mean Square.
Shoot	19	5,384·1	283·37	2·8235
Position on Shoot ..	21	12,489·9	594·76	3·1941
Error	399	10,727·6	26·89	1·6457
Total	439	28,601·6	—	—

total sum of the squares of deviations there is left 10,727·6, which may here be termed the " error ", since it is due to fortuitous fluctuations in the size of the leaves, associated neither with the shoot nor with position on the shoot. The complete analysis of variance is given in Table VI.

The values for " z " are therefore 1·1778 and 1·5584 for shoot and position respectively. As the value corresponding to P = ·05 would be about ·457, it is clear that these values are quite significant.

Although the mean area of the leaf was correlated with the position of the leaf on the shoot, the relation was not a simple one. The values for the twenty shoots included in the analysis of variance have been plotted in Fig. 13 where the abscissae denote the positions of the leaves, the ordinates their mean areas. The points representing the values for the latter have been connected by thin continuous lines. For comparison, the corresponding values for shoots of the same leaf number on No. IX have been plotted on the same figure ; these are connected by heavy continuous lines. In both curves the mean area is small at the apex, increases rapidly to a maximum at the fifth leaf, falls away to a minimum at the eleventh or twelfth leaf, rises rapidly to a second maximum at about the eighteenth or nineteenth leaf, then finally decreases very rapidly towards the base. In general form the two curves are very similar, and in the apical part of the shoot they practically coincide. In the region of the basal maximum, however, the curve for No. V is somewhat above that for No. IX. All the shoots on the No. IX had arisen from axillary buds, whilst seven of the twenty on No. V had arisen from terminal buds. To examine the possibility that the difference between the curves might be due to this difference in shoot position, the mean values for the seven terminal and the thirteen axillary shoots on No. V were determined and have been plotted on the figures. Those for the axillary shoots have been connected by a broken thin line, those for the terminal by a dotted line. Clearly the curve for axillary shoots on No. V coincides almost exactly with that for shoots of the same origin on No. IX ; the curve for the terminal shoots is widely divergent in its basal part, showing that basal leaves tended to be larger on terminal than on axillary shoots.

The corresponding values for the mean leaf area at each position on primary shoots with eighteen leaves have been plotted in Fig. 14, where the heavy continuous line refers to the tree on No. IX, the thin continuous line to that on No. V. The curves are of the same general form as those for shoots with twenty-two leaves, except that the apical maxima are much reduced in size. The corresponding values for secondary shoots on No. IX are plotted in the same figure and connected by a heavy broken line. There is a greater difference between the secondaries and the primaries on No. IX than between the primaries on the two trees. The secondaries tend to have larger leaves than the primaries towards the apex and smaller leaves towards the base. Possibly this may have been due to the different point of origin of the two classes of shoot ; the secondaries arose from fruiting spurs, many of which were actually bearing fruit which may have had a dwarfing effect on the leaves nearest them. The tree on No. V had no secondary shoots with eighteen leaves.

Curves have also been worked out for shoots with twenty leaves, but are not given here. They showed exactly the same general characteristics as those given, except that the apical maximum was intermediate in size. The curve for secondaries on No. IX was similar to that for those with eighteen leaves, but the apical maximum was actually considerably greater than the basal maximum. The difference between primary and secondary shoots, in the relation between leaf area and leaf position, seems an additional reason for regarding these two types of shoot as distinct categories which should be recorded separately in all measurements made on the shoots of a tree.

Examination of the primary shoots of other leaf numbers showed that these all tended to conform to the same general type ; there were the same two maxima, at the apex and base respectively, and the same marked minimum between them. The position of the basal maximum and of the minimum remained more or less constant but that of the apical maximum varied with the number of leaves. In shoots of higher leaf number the apical maximum became more pronounced and extended over a larger number of leaves, whilst in shoots of lower leaf number this maximum decreased until it tended to disappear altogether in shoots of about thirteen or fourteen leaves. Unfortunately there were too few shoots of these low leaf numbers for their leaf relations to be determined with precision.

The relation between leaf area and leaf position shown here is very different from that found by Swarbrick and Naik (28) in Worcesters. There is no trace here of three regions corresponding to a Sachs " Grand Period of Growth " ; the indication would rather seem to be that there was a period of slow growth between two periods of rapid growth. The difference between the relation found by the above authors and that described here may have been due to difference in climatic conditions, for the investigations were carried out in different years and at different localities. To determine the relations between leaf size and weather conditions, however, it would be necessary to carry out a more dynamic research and to record the date each leaf expanded, the period during which it grew and the date at which it attained its final area and to compare the weather conditions at these times with the final size of the leaf. It is more probable, however, that the difference is varietal. Certain visual observations were taken on other varieties on the same plot at the time this investigation was in progress, and it was found that although most of the varieties there conformed to the same type as Laxton Superb, with large leaves

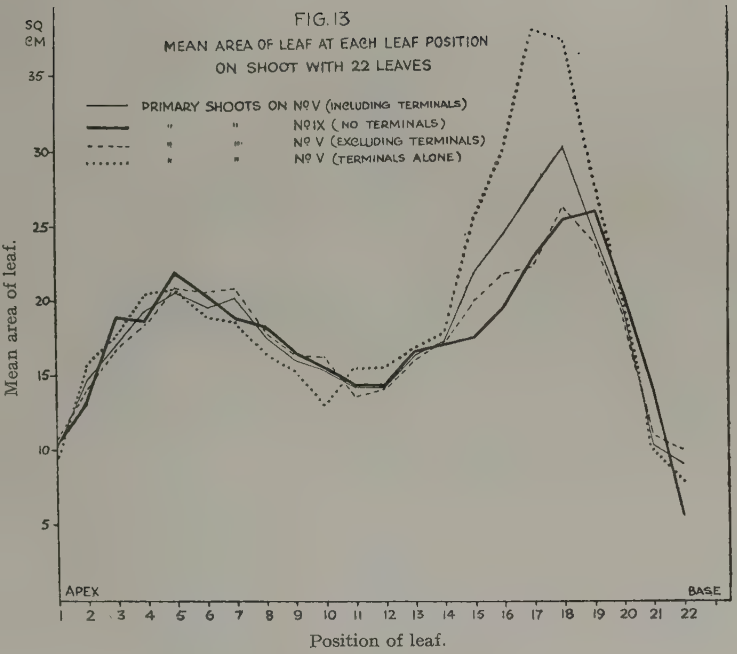


FIG. 13

MEAN AREA OF LEAF AT EACH LEAF POSITION ON SHOOT WITH 22 LEAVES

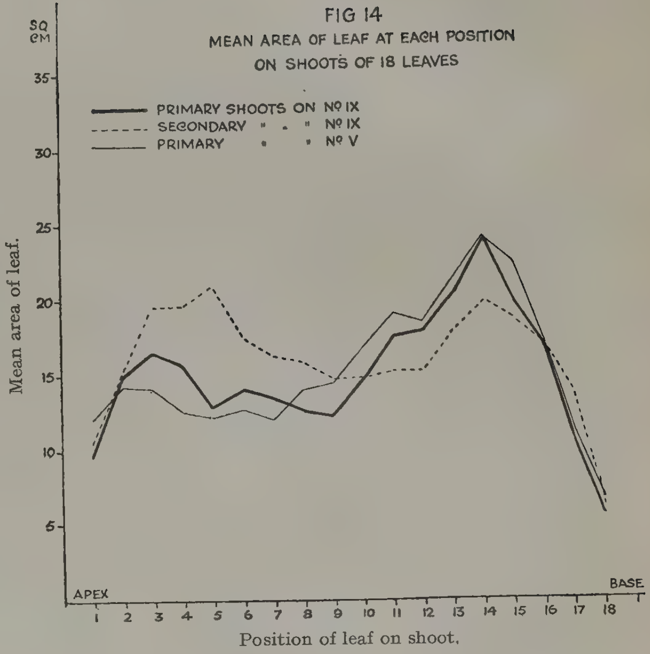


FIG 14

MEAN AREA OF LEAF AT EACH POSITION ON SHOOTS OF 18 LEAVES near the apex and base of the long shoots and smaller leaves between, there were other varieties, notably Upton Pyne, which did not show this characteristic. In these the range in leaf size along the shoot was similar to that found by Swarbrick and Naik in Worcesters ; there were small leaves at the base and apex and larger leaves on the remainder of the shoot.

9. *Co-efficients of Variability in Leaf Number and Leaf Area.*

The results of the morphological analysis of the growths into categories are summarized in Tables VII and VIII, which deal respectively with the number of leaves per growth and with the mean area of the leaf. A similar table could be prepared for the values of the mean length of stem ; but in view of the subsidiary importance of those values, from the point of view of the present investigation, this table has been omitted in the interests of economy and space.

In each table the values for the whole tree are given first and compared, then those for the primary and secondary growths. The primaries are then subdivided into the three categories, "bearing" spurs, "non-bearing" spurs and shoots.

The first column in each table specifies the type of growth included in the groups compared ; thus "whole tree" means that the growths of all types were included. Column 2 states the tree and column 3 the total number of growths (Table VII) or of leaves (Table VIII). The fourth column gives the mean values of the leaf number or leaf area, and when the difference between the two values of the mean are significant, they are printed in heavy type.

TABLE VII.

Mean Values and Co-efficients of Variability for Number of Leaves per Growth.

Category of Growth.	Tree.	No. of Shoots Measured.	Mean Number of Leaves.	Co-efficient of Variability.	Size of Sample required to show	
					10% dif.	20% dif.
Whole tree ..	IX.	1,468	**7·108**	68·65	377	94
	V.	2,053	**9·742**	82·05	539	135
Primary ..	IX.	789	**6·470**	57·93	268	67
	V.	1,847	**10·213**	79·81	510	127
Secondary ..	IX.	679	**7·850**	65·15	340	85
	V.	206	**5·544**	83·00	551	138
Bearing spurs	IX.	586	**5·283**	21·01	35	9
	V.	130	**5·777**	19·40	32	8
Non-bearing spurs ..	IX.	128	**4·234**	52·47	220	55
	V.	1,183	**5·413**	42·62	145	37
Shoots ..	IX.	75	**19·574**	16·48	20	7
	V.	534	**21·929**	20·14	32	8

TABLE VIII.

Mean Values and Co-efficients of Variability for Mean Area of Leaf.

Category of Growth.	Tree.	No. of Leaves Measured.	Mean Area.	Co-efficient of Variability.	Size of Sample required to show	
					10% dif.	20% dif.
Whole tree ..	IX. V.	9,156 17,978	**12·779** **17·70**	56·47 52·52	255 221	63 56
Primary ..	IX. V.	4,116 16,913	**10·702** **17·909**	67·22 52·48	362 220	91 55
Secondary ..	IX. V.	5,040 1,065	14·476 14·462	46·82 46·29	176 172	44 43
Bearing spurs	IX. V.	2,190 460	**7·038** **8·493**	21·75 42·67	38 146	10 37
Non-bearing spurs ..	IX. V.	529 5,877	**9·353** **16·171**	76·32 62·74	466 394	117 99
Shoots ..	IX. V.	1,397 10,576	**16·956** **19·275**	42·93 45·27	148 164	37 41

The co-efficients of variability are given in column 5, while the size of samples that would be required, on the basis of these co-efficients, to prove differences of 10 per cent and of 20 per cent respectively between two mean values are given in the last two columns of the tables.

These tables have been prepared primarily to serve as the basis for sampling methods. For example they show that a count on at least 500 primary shoots would have to be made if it was required to prove a difference of 10 per cent between the mean values for leaf number in two trees. In the case of bearing spurs, however, a count on thirty-five spurs might be sufficient.

In view of the rather wide differences sometimes found between the values for the two trees, it would probably be wiser to use samples at least 50 per cent larger than those given in columns 5 and 6.

Various sampling methods based on these data are being tried, but no description of them will be given until they have been thoroughly tested in the field.

10. *Estimated Total Leaf Surface.*

The values for the total area given in Table II, were the summed areas of all the measured leaves. As already mentioned, however, some leaves were either too badly damaged to measure or had already fallen, being represented only as scars. When estimating the total leaf surface developed on each tree these unmeasured leaves should be taken into account.

An estimate of the total leaf surface can be made by multiplying the mean area, found from the measured leaves, by the total number of leaves including those not measured. Such an estimate assumes that the mean area for leaves not measured was the same as for those whose areas were determined. It has been shown, however, that the mean area of the leaf was not the same in different categories of growth. It was smaller, for instance, in " bearing " spurs than in primary shoots. It has also been shown that, within each category, growths with few leaves had, on an average, smaller leaves than those with several leaves. If, therefore, the proportion of leaves measured was different in different categories or on growths bearing different numbers of leaves, then, for the tree as a whole, the mean area of the unmeasured leaves would not be the same as that for those measured.

To obtain some estimate of the magnitude of the effects of these possible sources of error, the total leaf surface on each tree has been estimated in three different ways.

(i) The total number of leaves on the tree has been multiplied by the mean leaf area for the tree as a whole.

(ii) The total number of leaves in each category of growth has been multiplied by the mean area for leaves in that category.

(iii) The total number of leaves borne on growths of each leaf number, within each category, has been multiplied by the appropriate values for the mean leaf area.

The values for the total leaf area, found by these three methods of estimation, are given in Table IX.

TABLE IX.

Estimated Total Leaf Surface. (Mean Area of Leaf) × (Number of Leaves).

		Bearing Spurs.	Non-bearing Spurs.	Primary Shoots.	Secondaries.	Total.
By Categories ..	IX.	21,789	5,070	24,892	77,157	128,908
	V.	6,379	103,542	225,747	16,517	352,185
By Groups of same Leaf No.	IX.	21,767	5,072	24,855	77,177	128,871
	V.	7,252	104,025	225,613	16,550	353,440
From Tree as Whole	IX.	—	—	—	—	133,366
	V.	—	—	—	—	354,130

The values found by the three methods of estimation agree fairly closely, except in the case of the bearing spurs on No. V. Leaf fall from these growths was apparently especially associated with spurs of certain leaf numbers.

There is another potential source of error that may affect the values of the estimate, this is the effect of leaf position. Leaves in certain positions, such as those towards the base of growths, tended to be smaller than the others. As there was probably a tendency for basal leaves to fall before those in other position, it is probable that the mean areas of the unmeasured leaves were really rather less than those of the measured leaves, and the values for the total area given in the table are probably over-estimated on that account. No attempt has been made to estimate the effect of this course of error on account of the disproportionate amount of labour it would involve.

11. *Relative Effects of Various Morphological Factors.*

The total leaf surface found on the No. V was 318,232 sq. cm., that on the No. IX was 117,008 sq. cm., the ratio of the leaf surface on the one tree to that on the other was thus 2·7197 : 1·0000. On growths of particular categories, the differences between trees were even greater. Thus the leaf surface found on " non-bearing " spurs was 95,036 sq. cm. on the No. V and only 4,948 sq. cm. on the No. IX. The ratio V : IX being therefore, 19·2069 : 1·0000.

These differences in total leaf surface are clearly the result of the action and interaction of a number of morphological differences between the trees. For example, they are due partly to differences in the mean areas of the leaves on the two trees, partly to differences in the numbers of leaves. An attempt will now be made to estimate the relative effect of these various factors.

If " L " is the total leaf surface found on a group of growths, such, for instance as the " non-bearing " spurs on No. V, then it can easily be shown that

" L "=" ABCDE," where

" A " is the total number of growths on the tree,
" B " the proportion of these included in the group,
" C " the mean number of leaves borne on a growth,
" D " the proportion of these measured, and
" E " the mean area of the leaf.

For the product of the total number of growths on the tree " A " and " B ", the proportion included in the group, will give the actual number of growths in the group.

The product of this actual number " AB " and " C ", the mean number of leaves on a growth, will give the total number of leaves borne by the growths included in the group.

Similarly the product of this total number of leaves, " ABC " and " D ", the percentage of these measured, will give the actual number measured.

Finally the product of the number of leaves measured " ABCD " and " E ", the mean area of the leaf, gives the total surface.

If " L, A, B, C, D " and " E " represent the values of these various quantities for the tree on No. V, and " L′, A′, B′, C′ ", etc. the corresponding values for the tree on No. IX, and if the small letters, " l, a, b, c, d ", etc. denote the values of the ratios " L/L′ ", " A/A′ ", " B/B′ ", " C/C′ ", etc., it is obvious that

" l " = " abcde ".

The values of " a ", " b ", " c " represent the relative effects of the various morphological factors upon the ratio of the leaf surface on the one group of growths to that on the other. Each represents the value of " l " that would have been found had the two groups differed solely in that one factor.

The values for these ratios, " a, b, c ", etc. are therefore given in Table X, and provide a measure of the relative magnitude of the contributions made by the various morphological factors to the differences in leaf surface found between the two trees.

The first column of values refers to the trees, each taken as a whole; the other four columns refer respectively to four categories indicated at the top of each.

Taking each tree as a whole, the values of " A " and " A′ " (the total numbers of growths) were 2,053 and 1,468 respectively, the value for " a " or " A/A′ " is therefore 1·398501. Had the trees differed only in their relative numbers of growths, the ratio of the leaf area on No. V to that on No. IX would likewise have been 1·398501.

All the growths on each tree are included, when the whole trees are thus compared, hence the value of " b " or " B/B′ " is unity.

The number of leaves per growth was 9·74476 on the No. V and 7·10899 on the No. IX, the ratio " C/C′ " or " c " is therefore 1·370766. This is a ratio that the leaf area on the one tree would have borne to that on the other, if the trees had differed solely in the number of leaves per growth.

The percentage of leaves measured was 89·8630 on the No. V and 87·7348 on the No. IX; the value of " d " is hence 1·024257. The mean area of the leaf was 17·70119 sq. cm. on the No. V and 12·77938 on the No. IX; which makes the value of " E/E′ " or " e ", 1·385137.

At the base of the column is given the value of " abcde " which is, of course, the same as the value of " l " or " L/L′ ". This represents the combined effect of the action and interaction of all five factors.

Comparing the whole trees in this manner, it is evident that differences in the percentage of leaves measured had little effect and that differences in the numbers of growths, in the number of leaves per growth and in the mean area of the leaf, had each an effect of about the same order on the relative total leaf surfaces on the two trees.

When dealing with the various categories of growths separately, in the other four columns, the values for " b " become very important. For example, in the case of the " bearing " spurs ; only 130 of the total of 2,053 growths belonged to that category on the No. V ; the value of " B " was therefore 6·332197 per cent. Whilst 586 of the 1,468 growths on No. IX were of that type ; making " B′ " 39·918256 per cent. The resulting value of " b " is therefore ·1586291. In all the categories the values for " b " are either very high or very low which means that the values of " l " would likewise have been high or low, had differences in the proportional distribution of growths, between the various categories, been the only difference between the trees.

The value for " e " is fairly high in the case of the " non-bearing " spurs, showing that difference in mean size of the leaf was there an important contributory factor. But in every category the value for " b " forms the most important individual difference between the trees.

Table X.

Values of the ratios $\frac{V}{IX}$ *for the various Morphological Factors.*

	Factor.	Whole tree.	Bearing Spurs.	Non-bearing Spurs.	Primary Shoots.	Secondaries.
a	Total Growths per tree ..	1·398501	1·398501	1·398501	1·398501	1·398501
b	Proportion included ..	1·000000	0·158629	6·608640	5·091164	0·216938
c	Leaves per Growth ..	1·370766	1·093436	1·278231	1·120343	0·706222
d	Proportion measured ..	1·024257	0·865914	0·940407	0·949061	0·986234
e	Mean Area	1·385137	1·206870	1·728854	1·136931	0·999096
abcde	Total Area ..	3·719742	0·253498	19·206949	8·607145	0·211118

B. *Relative Fruitfulness of the Two Trees in the Current Year.*

Not only was the number of bearing spurs determined on each tree but records were made of the numbers of blossom scars, fruit scars, aborted fruit and of fruit. These records are summarized in Table XI.

The " Number of Fruit Present " denotes the number of developing fruit actually found in position on the trees in the course of the investigation. These values will be biassed in favour of the tree on No. IX, for this tree was measured

TABLE XI.

	IX.	V.
Number of Fruit Present	209	45
Scars and aborted Fruit	1,729	353
Estimated Number of Blossom	1,938	398
Number of Bearing Spurs	586	130
Estimated Blossom per Spur	3·3	3·1

first. Fruit were continually dropping from both trees throughout the investigation, the number on No. V will have been reduced relatively more from this cause than that on No. IX.

The combined number of fruit and of scars, however, will not have been influenced by this time factor and provides an estimate of the total number of blossom produced on the trees. It is probably an under-estimate, however, because several circumstances may lead to a scar being missed. For example, where two or more fruit were still attached to the spur, it was often impossible to determine the exact number of scars as the spur was hidden between the fruit. The thickening base of the stalk of a developing fruit may obliterate neighbouring scars on the same spur; the tip of a spur had sometimes gone, apparently as a result of abscission, and was represented by a large scar where there may originally have been several distinct blossom scars.

The number of blossom per spur seems to have been about the same on both trees, but the tree on No. IX had more than four times as many bearing spurs than that on No. V. Even allowing for a greater drop of fruit from the No. V there seems no doubt that this tree bore a far smaller crop than the No. IX. This is brought out also by Fig. 3 which is a photograph taken at the end of the investigation.

C. *Stem Relations in Wood of Past Years.*

I. *Relative Lengths and Numbers of Surviving Growths.*

The summed lengths of the wood of each year from 1925 until 1930 have already been given in Table I. These values represent the amount of wood of each year that had survived all pruning operations and accidents, and was still alive; dead spurs were occasionally found but were not included in these values. (These values are shown diagrammatically in Fig. 15 where the total heights of the columns represents the lengths of wood.) There were considerable fluctuations from year to year in the amounts of wood contributed to the framework of the tree; for example the amount contributed in 1930 was less than that in 1929, the amount in 1927 less than that in 1926. These fluctuations are

FIG. 15

SUMMED LENGTHS OF SURVIVING WOOD OF PAST YEARS

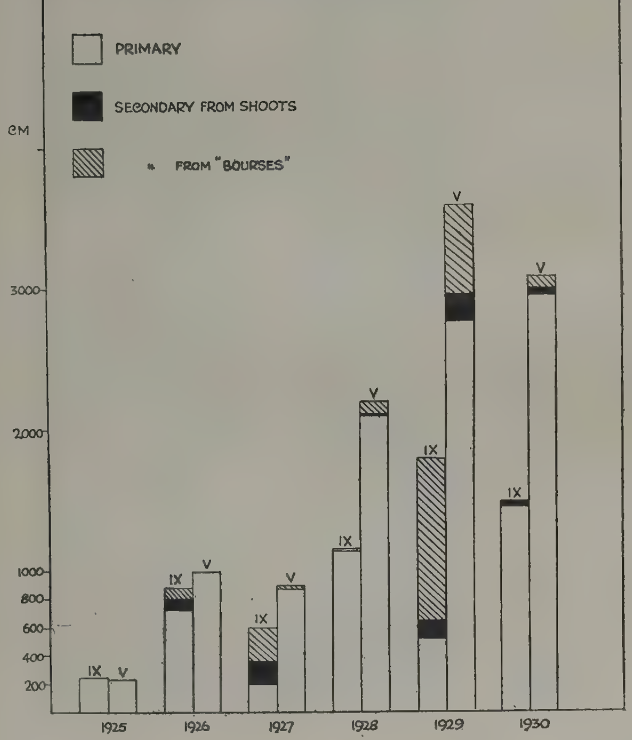
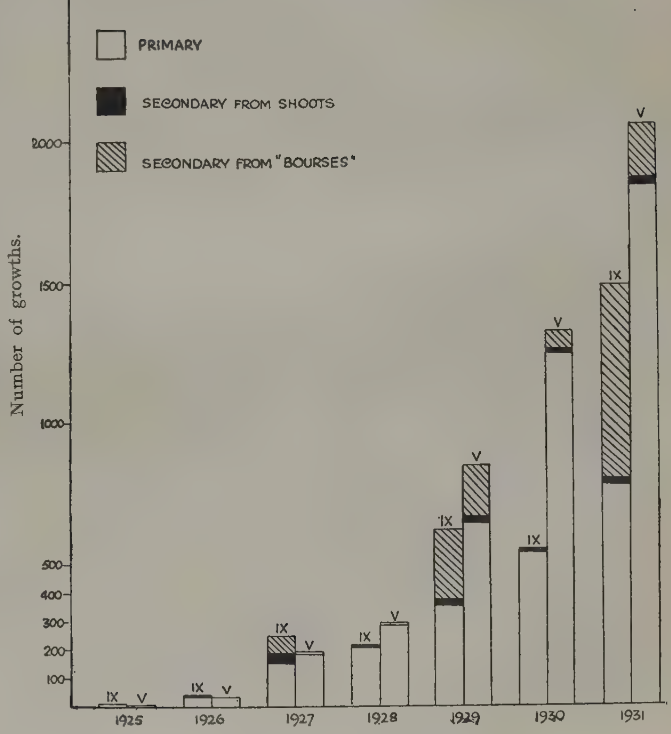


FIG. 16

NUMBER OF GROWTHS OF EACH YEARS ORIGIN SURVIVING IN 1931



shown graphically in Fig. 17 where the length of each year's wood has been expressed in terms of that of the previous year. The values for the two trees show exactly the same fluctuations though those for the tree on No. V are always slightly the higher, indicating that that tree was growing consistently the faster. This is brought out more clearly in Fig. 18 where the length of each year's wood on No. V is given as a ratio of that on No. IX for the same year. Pruning may, however, have a selective effect, it will reduce the length of leaders more than that of spurs. It would reduce the value of the summed length of growths more in a tree with many shoots than in a tree with fewer shoots. Some indication of this can be obtained by taking the number of growths instead of their summed length. Table XII gives the total number of growths on each tree for each year's wood; these values include both the primary growths and the secondary.

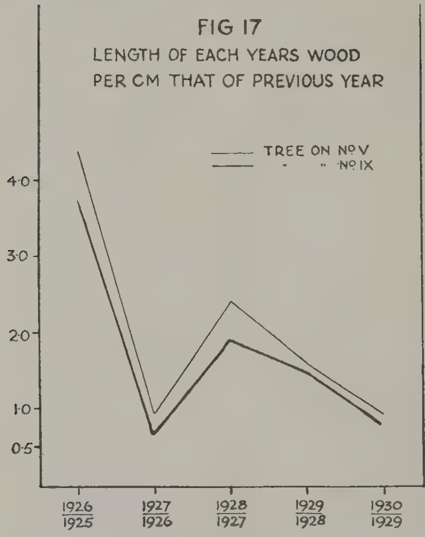


FIG 17
LENGTH OF EACH YEARS WOOD PER CM THAT OF PREVIOUS YEAR

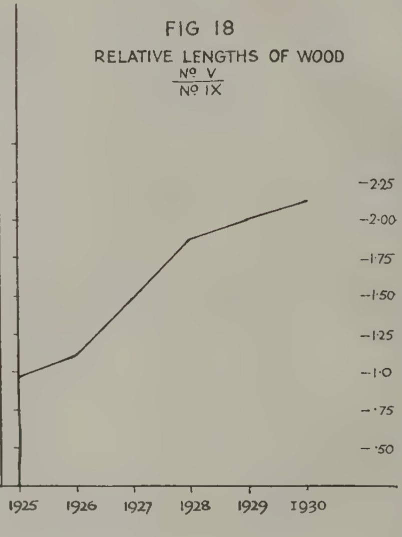


FIG 18
RELATIVE LENGTHS OF WOOD Nº V / Nº IX

TABLE XII.

Number of Surviving Growths of Each Year's Wood.

	1925.	1926.	1927.	1928.	1929.	1930.	(1931.)
IX. ..	5	39	240	212	621	575	(1468)
V. ..	7	28	176	287	849	1318	(2053)

2. *Relative Amounts of Primary and Secondary Growth.*

It has been seen that there were great differences between the trees in the relative amounts of primary and secondary wood formed in the current year, and that the differences in the number of " bourse " secondaries on the two trees was related to, and probably the result of, the different number of bearing spurs. It is of interest to determine the relative amounts of these two types of growth in past years. In Figs. 15 and 16, which give respectively the summed lengths and the numbers of growths of each year's wood, the columns have been divided into three portions. The basal portion, unshaded, refers to the primary growths ; the uppermost portion, cross-hatched, refers to the " bourse " secondaries, whilst the intermediate portion, black, refers to the " shoot " secondaries. The values given in Fig. 15 are not strictly comparable to those for 1931, since they refer to wood surviving after pruning ; those given in Fig. 16, however, may be more legitimately compared with those of the current year since they deal solely with numbers, the values for that year have therefore been included. The values for shoot secondaries are probably an under estimate in both figures. Most of such growths arise in the more apical part of primary shoots and will be automatically removed in the process of pruning, except where they have arisen as a result of injury to the primary shoot, whose extension growth they have continued.

It will be seen in Fig. 16 that the number of primary growths increased each year on both trees, though the rate of increase was relatively greater on the No. V.

The proportion of " bourse " secondaries on No. IX is of particular interest ; these growths formed the greater part of the total surviving length of wood and were relatively very numerous in the years 1929 and 1927, just as in 1931 ; but were negligible in amount and number in the alternate years 1930 and 1928. As this type of growth arises from bearing spurs, the alternation strongly suggests biennial bearing. Full records of blossoming and fruiting are unfortunately not available for these trees, but there are blossom records for 1928 and 1929 and crop records for 1927 and 1930. These show that there were no blossoms on the No. IX in 1928 and no fruit in 1930 ; whilst in 1929 there were 155 blossom trusses of which 144 were " spur " and in 1927, seventy-two fruits were picked from the tree. Thus the yearly alternation of high and low proportions of " bourse " secondary growths corresponds to a similar alternation in number of blossoms or of fruit borne on the tree. There is thus some evidence that the amount of " bourse " secondary shoots is closely related to the number of blossoming bourses, and, *a priori*, this might have been expected.

In the spring of 1932, at the time this paper was prepared for publication, there was again very little blossom on the No. IX, so that the inverse relation between the amount of blossom and the amount of bourse secondary wood of the previous year has been continued. The tree on No. V, however, has a large amount of blossom.

VI. DISCUSSION.

It has been shown that the two trees differed widely in their total leaf surface, in the number of leaves they bore per growth and in the main areas of their leaves.

It has also been shown that these differences were largely a result of differences in the relative proportions of the various types of growth borne on the two trees.

The small-leaved " bearing " spurs were far more numerous on the No. IX, and as a consequence this tree had also a smaller proportion of the larger-leaved primary " non-bearing " spurs and shoots. The resulting difference in total leaf surface was only partially compensated for by the larger number of large-leaved secondary growths present on the No. IX.

As " bearing " spurs are those developed from " fruit " buds formed the previous season, and " non-bearing " primary spurs and shoots are the growths that have developed from the " leaf " buds of the previous season, it is clear that much of the difference in area between the trees was predetermined by the relative proportions of these two types of bud.

There were, however, significant differences in leaf number and area even within the same types of growth. For example the tree on No. V had very much larger leaves than the tree on No. IX on the primary non-bearing spurs. These differences may have been the result of the heavier crop borne on the No. IX for there is evidence that the presence of a crop may dwarf the leaves on even vegetative growths, e.g. Swarbrick (27).

The differences between the trees could not have been determined by a sampling method unless precautions had been taken to sample from each type of growth separately, and to determine the relative numbers of these different types. The main conclusion to be drawn from the results of this investigation, is the necessity for taking these precautions.

The widely different proportions of spurs and shoots on the two trees suggests the desirability for counting the number of spurs as well as recording the length of the shoots when measuring the wood growth of a tree. An estimate of their combined length could be obtained by measuring the lengths of a random sample of spurs where it was impracticable to determine the length of each individually.

The difference in the relative proportions of spurs and shoots on different stocks and in fruiting and non-fruiting years has, of course, long been well-known to pomologists, but for practical reasons, wood measurements have generally been confined to the length of shoots.

In conclusion, it must be emphasized that this investigation was made on only two trees and that these differed not only in the rootstock upon which they were worked but also in their fruiting condition, in the year of the investigation.

The main object of the investigation was not to establish the existence or otherwise of differences in leaf relations of trees on different stocks, or in different fruiting condition, but rather to explore the possibility of carrying out such an investigation in the future. It was aimed at determining the magnitude of the differences to be expected between trees and at estimating the amount of variability that would be found within trees. In both these respects the investigation has yielded useful results which will be employed in the development of sampling methods for further exploration of leaf relations in fruit trees.

VII. SUMMARY.

(1) The length, character and position of every growth and the size and position of every undamaged leaf was measured on two trees (Laxton Superb) one of which was on the dwarfing Malling Stock No. IX and bearing a heavy crop, the other on the vigorous Malling Stock No. V and bearing a light crop.

(2) The leaf measurements were made by a new method described in full.

(3) The growths were separated according to their nature into (a) Primary spurs that had borne blossoms, (b) primary non-bearing spurs, (c) primary long shoots and (d) secondary growths.

(4) Within these categories growths were grouped according to the number of their leaves.

(5) On each tree, the size of the leaf varies with (a) the nature of the growth bearing it, (b) the number of leaves on the growth, and (c) the position of the leaf on the growth.

(6) On long shoots the largest leaves occurred near the apex and the base, those in the intermediate positions and at the extreme apex and base being smaller. The magnitudes and positions of the maxima were different on primary and secondary shoots.

(7) The mean length of stem, the mean internode length, and the mean and total leaf areas were greater on the No. V than on the No. IX, but the leaf area per unit length of stem was less.

(8) The greater total leaf area on the No. V was due, (a) partly to a larger total number of growths, on that tree, (b) partly to a smaller proportion of small-leaved " bearing " spurs, (c) partly to growths with large leaf numbers being more numerous, and (d) partly to the mean size of the leaf being greater in all categories except the secondaries.

(9) Examination of the surviving stems of past years' growth revealed a regular alternation in the relative amount of primary and secondary stems on the No. IX which was directly associated with the recorded fruiting and blossoming performance of that tree.

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(*Received* 9/9/32.)

FURTHER STUDIES ON THE INCIDENCE AND CONTROL OF APPLE SCAB (*VENTURIA INÆQUALIS*) AND APPLE MILDEW (*PODOSPHAERA LEUCOTRICHA*) AT EAST MALLING.

By M. H. MOORE.

East Malling Research Station, Kent.

INTRODUCTION.

A FULL account of the first three years' work on this investigation, covering the period from November 1926 to September 1929, has already been published (2). The experiments were designed primarily to determine the importance of the following points in successful Scab- and Mildew-control on the susceptible Cox's Orange Pippin apple.*

(a) time of application of sprays ;
(b) number of applications ;
(c) strengths that could safely be used ;
(d) relative merits of different fungicides.

As the work progressed, certain points were established regarding successful control of these two diseases. The main conclusions reached are repeated here, for it will be shown that the present data largely support those conclusions.

It was abundantly clear that, with spore-production mainly occurring just before, or during, blossom-time, the early leaves and the flowers must be effectively protected to prevent Scab from becoming established at the critical blossom-period, when spraying with strong fungicides is inadvisable. The results, in fact, showed that a " pink-bud " application of Bordeaux mixture or of lime-sulphur was of great importance in preventing early leaf-infection. Fruit crops were slight up to the end of 1929, for the trees had not reached full bearing, but, in spite of this, it was shown that Bordeaux mixture (at 8-8-100) was unsafe on Cox's Orange Pippin, even at " pink-bud ", because of severe fruit-russeting. Post-blossom applications (at 8-25-100) also caused severe leaf- and fruit-injury. Weak post-blossom sprays such as lime-sulphur at 1-100, though inadequate alone, continued to protect the leaves, fruits and young shoots where early infections were prevented by lime-sulphur, applied pre-blossom, at 1-30.

Three applications of lime-sulphur, the first (1-30) at " pink-bud ", the second (1-100) at petal-fall and the third (1-100) three weeks later, gave excellent control of Scab and Mildew without causing injury. Particular care was taken to ensure thorough application of sprays so that good " cover " was provided. Care in application may possibly be vital, for these three sprays withstood the test of conditions under which neighbouring " control " trees became heavily infected.

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* Interplanted Stirling Castle trees were formerly included in these spraying trials, but they showed so much damage from sulphur-sprays that the trees were not used after 1928.

The inclusion of lead-arsenate paste (0·4 per cent) for insecticidal purposes was highly satisfactory. Caterpillar-attacks were checked by the combined spray, and evidence was obtained that its fungicidal value was probably enhanced.

It was shown that Scab- and Mildew-susceptibility in the scion was influenced by the variety of rootstock, and there were indications that " tree-condition ", as governed by cultural operations and by the type of season, might be an important factor in the success of any spraying scheme.

A fourth year's results are discussed in the present paper. They were obtained in 1930, after which the experiments were replanned in order to develop other aspects of the problem which had arisen as the work proceeded.

While, in the earlier years, records had necessarily been made only of shoot- and leaf-infection, there were prospects in spring, 1930, of heavier and more uniform cropping. All possible data on the fruit-crop were therefore obtained, other records being made only as time allowed.

On account of the unexpected and unexplained damage in 1929 caused by Bordeaux mixture made with hydrated lime, freshly-burnt quick-lime was again used in 1930. Apart from this, the sprays used were the same as before.* The method of application, however, differed considerably. Although, formerly, a knapsack machine, yielding a delivery pressure of approximately 60 lb. per square inch, had conveniently been used, this was not possible in 1930 on account of the increased height of the trees. A horizontal barrel machine, hand-operated, was therefore obtained, and no difficulty was then found in providing adequate " cover " when other conditions were favourable. The lance was of the " spray-gun " type, and it was regulated to give a " misty " spray at a delivery pressure of 200-220 lb. per square inch.

Times of Spray-application and Notes on Weather Conditions.

The pre-blossom application was made on May 9th, at the " pink-bud " stage, the unopened flowers being well separated (see (1) Fig. 1). Each truss was surrounded by fully-developed leaves, and terminal wood-buds showed partially-expanded leaves. As far as could be seen, there were then no new Scab-infections on either previously sprayed or unsprayed trees. During application, the weather was moderately warm and cloudy, with a fairly strong south-west wind not ideal for obtaining perfect " cover ". Bright intervals occurred, and a light shower fell when the lead-arsenate was being applied to the "controls". Steady rain followed in the night, but the sprays had become dry before this. Next day was fine but cool, with fresh S.W. breezes.

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* The general arrangement of the trials was fully set out in a previous paper (2).

Only Bordeaux mixture (8-8-100), with or without lead-arsenate (0·4 per cent), caused damage at this period. Scorched patches appeared on some of the rosette leaves, certain of which dropped two or three weeks afterwards, but this was not serious. Negligible scorching was noted around the margins of leaves that received lime-sulphur (1-30) with lead-arsenate (0·4 per cent).

The first post-blossom spray was applied on May 27th, when most of the petals had fallen. Weather conditions, on the whole, were favourable, Bordeaux mixture (8-25-100) with lead-arsenate (0·4 per cent) being applied in hot sunshine and lime-sulphur (1-100, with arsenate 0·4 per cent, and 1-150, with "spray"-gelatine 0·1 per cent) in warm, dull weather. The remaining sprays, which included colloidal sulphur (0·4 per cent) with "spray"-gelatine (0·1 per cent), gelatine solution (0·1 per cent) and lead-arsenate (0·4 per cent), were applied in bright weather with brief, cloudy intervals.

The second post-blossom spray was applied on June 19th in similar weather to that on May 27th. On this occasion, also, it was possible to apply lime-sulphur while the sky was somewhat overcast. The strengths of sprays were the same as for the first post-blossom application.

Towards the end of June, the trees were carefully inspected and the following general observations recorded: "Recent observations on the incidence of Apple Scab have shown similarity between the development of the disease in 1930 and in 1928. The spring weather, also, in 1930, was similar to that in 1928, for fairly wet weather in May induced severe infection on control trees during and just after blossom. Where lime-sulphur (1-30) or Bordeaux mixture (8-8-100) was applied, at 'pink-bud', this early infection was checked, and weaker post-blossom applications have, since then, kept the trees clean. All trees not fungicidally sprayed are now showing severe leaf- and fruit-infection. Recent deficiency of rain appears to have been supplemented by heavy dews, for existing Scab-infections are still developing in spite of apparent absence of moisture. Leaves and fruits severely infected early in the season are now dropping, and some are even withered by heavy infection."

OBSERVATIONS ON ASCOSPORE-DISPERSAL AND SUBSEQUENT INFECTION.

Scabbed Bramley's Seedling and Worcester Pearmain leaves were again collected, in autumn, 1929, and kept in a wire cage under natural conditions during the winter 1929-30. Perithecia developed on these leaves in spring, 1930, and the first ripe ascospore was found on April 17th, when apple trees were approaching the "pink-bud" stage. The main production of ripe ascospores did not occur until the end of the month.

On April 17th a hessian screen, on cane supports, was erected around a small, "unworked", bush tree of Malling No. VIII apple rootstock, and the scabbed leaves, in the wire cage, were placed at the base of the tree inside the screen. Very severe Scab-infection occurred while the tree was in bloom. This developed rapidly post-blossom, probably because of wet weather in May, and, by the middle of June, the tree was almost defoliated. There is little doubt that this heavy infection was initiated by ascospores shot from the dead leaves, as neighbouring trees remained Scab-free until much later.

Wet periods during August undoubtedly induced a wave of "secondary" Scab-infection. Sprayed Worcester Pearmain fruits that had remained Scab-free throughout the summer developed appreciable infection within a week or so of picking. Fruits of Bramley's Seedling and of certain other varieties developed late infection at approximately the same time. Individual infection-spots were small, but sufficiently numerous to detract from the general high grade of the fruits. Worcester Pearmain and Bramley's Seedling fruits developed this late infection to a greater extent on No. V rootstock than on any other concerned in these observations.

GENERAL PROCEDURE ADOPTED IN RECORDING OBSERVATIONS.

The numbers of blossom-trusses, and of 1929 Mildew-infections that appeared at bud-break in 1930, were recorded at blossom-time. The fruits "set"—i.e. the number of blossoms effectively fertilized—were counted on certain representative branches of each tree. These figures formed the basis of conclusions reached concerning fruit-drop. The number of mature fruits on these branches was recorded later, when fruit-drop had ceased. Each week, post-blossom, *all* dropped fruitlets, including very small ones, were counted and graded for Sawfly and Scab. This was continued until picking-time. When they had reached marketable size, that is, from the middle of August onwards, all fruits that dropped (and there were very few) were counted as picked.

Detailed records were made on the crop from each tree. These included an estimate, obtained by the "category" method* (fully described in a previous paper (2)), of the approximate area of Scab on each fruit and of the severity of russeting. Brown rot (*Sclerotinia fructigena*)-infections were also counted and sub-divided into "primary" (the result of direct natural infection) and "contact" infections (due to contact of healthy fruits with those already attacked).

The leaves on each tree were examined once, in mid-July, nearly a month after the final spray-application, and an estimate of the relative Scab-infection was obtained. Scab-infection on the young shoots was not recorded in 1930.

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* Figures resulting from this method of Scab-grading bear no intrinsic value such as percentages do. They are merely a means of direct comparison between the approximate areas of Scab on the fruits of any two or more trees.

SYMBOLS USED IN DISCUSSION OF RESULTS.

The following symbols are used for the different sprays :—

B.M.A.—Bordeaux mixture + lead-arsenate.
L-S.A.—Lime-sulphur + lead-arsenate.
L-S.G.—Lime-sulphur + " spray "-gelatine.
C.S.G.—Colloidal sulphur + " spray "-gelatine.

DISCUSSION OF RESULTS.

PART IV.*

I. CONTROL OF APPLE SCAB.

(Variety—Cox's Orange Pippin.)

(*a*) *Percentage of Infected Fruits in Entire Crop*† (*dropped*‡ *and picked*).

Table I sets out the averages of results obtained on similarly-sprayed trees. Those bearing less than 20 fruits were not classified.

" Pink-bud " application. One of the most noteworthy of former results in these trials was proof of the great value of applying Bordeaux mixture (8-8-100) or lime-sulphur (1-30) at this period. Indeed, the " pink-bud " application was deemed vital to successful Scab-control, for *early* infection was prevented and a cumulative beneficial effect resulted.

The present results amply confirm this view, for where only a " pink-bud " application was made, the percentage (of the whole crop) of Scab-infected fruits was greatly reduced in comparison with the controls. B.M.A. (8-8-100) was more efficient than L-S.A. (1-30). With either spray, the percentage of infected fruits dropped was never *more* than that picked ; in most cases it was much less. On *control* trees (arsenate-sprayed), however, this did not always hold good, thus indicating that lack of *early* Scab-control caused early loss of crop. (Later fruit-infection does not normally cause fruit-drop.)

Two post-blossom applications. Both B.M.A. (8-25-100) and L-S.A. (1-100) reduced the percentage of infected fruits to about the same extent as the single, pre-blossom, spray, with B.M.A., again, slightly the more effective. On *all* trees, the percentage of infected fruits dropped was never *less* than that picked ; in most cases it was much more. Lack of *early* control is therefore reflected in

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* Part I (Apple Scab) appeared in (2) page 230, Part II (Apple Mildew) page 283 and Part III (Spray-Injury) page 290.

† " Entire crop " implies *all* fruits produced during the season. The figure for each tree was obtained by adding the number of fruits picked to that of fruits and fruitlets dropped from petal-fall to picking.

‡ The average diameter of representative samples of dropped fruits was obtained at each gathering. On June 26th, the average diameter (excluding all very small fruitlets) was 12·8 mm., on July 3rd, 19·2 mm., on July 9th, 25·5 mm. and on August 5th, 28·4 mm.

TABLE I.

Percentage of Infected Fruits in Entire Crop (1930).

(*Variety—Cox's Orange Pippin.*)

Stock.	No. and Time of Spray-applications.†	Average total crop produced per tree.			Average percentage dropped with Scab per tree.			Average percentage picked with Scab per tree.			Average percentage of entire crop with Scab per tree.		
		B.M.A.	L.-S.A.	A.	B.M.A.	L-S.A.	A.	B.M.A.	L-S.A.	A.	B.M.A.	L-S.A.	A.
I.	One pre-blossom ("pink-bud")	125	397	213	4	10	30	11	20	32	15	30	62
II.		249	387	371	9	11	34	9	22	24	18	33	58
IX.		155	193	235	2	5	24	11	20	35	13	25	59
XVI.		123	177	97	7	12	51	14	14	14	21	26	65
V.	Two post-blossom ..	148	449	299	11	17	47	7	5	17	18	22	64
XIII.		168	308	302	9	17	33	8	5	19	17	22	52
XV.	One pre- and two post-blossom	31	100	133	0	3	13	3	0	6	3	3	19
III.		103	440	371	1	3	26	0	3	28	1	6	54
IV.*		126	374	229	2	4	25	2	4	18	4	8	43
		L-S.G.	C.S.G.	G.	L-S.G.	C.S.G.	G.	L-S.G.	C.S.G.	G.	L-S.G.	C.S.G.	G.
VI.	Two post-blossom ..	137	147	145	16	13	30	5	10	27	21	23	57
X.		249	169	158	16	25	30	7	11	32	23	36	62

* Same sprays without lead-arsenate on No. IV stock. Few trees.

† The strengths of sprays will be found in the text.

these figures also, and the deductions from previous results (2) are justified—that efficient Scab-control is greatly dependent on the initial protection which a "pink-bud" application affords. This is especially so when weather favouring Scab-development occurs around blossom-time, as in 1930.

A higher percentage of infected fruits was *picked* from B.M.A.-sprayed than from L-S.A.-sprayed trees (on stocks No. V and XIII), although, on the whole, B.M.A. proved slightly the more efficient. As a result of fruit-drop from post-blossom spraying with L-S.A. (as shown by another set of figures), it is highly probable that certain *infected* fruits dropped when normally they would not, thus reducing the number of infected fruits ultimately picked from L-S.A.-sprayed trees.

Very weak L-S. (1-150) G. proved slightly superior to C.S. (0·4 per cent) G. in reducing the percentage of the total crop infected. Here again, lack of early Scab-control is shown by the greater percentage of infected fruits dropped than picked.

Three applications, one pre-blossom, and two post-blossom, of B.M.A. and of L-S.A. gave excellent Scab-control, as shown, also, by the "category" method (Table II). These three applications have shown a high degree of control in all four seasons, and they are regarded, therefore, as the basic Scab-spraying programme for conditions at East Malling. B.M.A. undoubtedly gave better Scab-control than L-S.A., but its tendency to damage Cox's Orange Pippin (see Part VI), and its inferiority to lime-sulphur in controlling Red Spider and Apple Mildew, make it the less desirable for use commercially.

Three applications of either fungicide without lead-arsenate (on trees on No. IV stock) also gave good results, though scarcely as good as with arsenate (on trees on No. III stock). There are few trees on No. IV stock, and the validity of this inference is thus lessened, although, having been noted before (2), the result is strongly suggestive.

(*b*) *Relative Area of Scab on Picked Fruits* (*by "category" method*).

Reference to the figures may be made in Table II.

Note.—To give an idea of the degree of infection represented by the "Scab-equivalents" in this table, 5 (and under) may be regarded as light, while 15 (and over) is heavy; 25 is very severe. Such relations are not necessarily true of the figures previously published (2), for different methods of calculation were used.

A single, "pink-bud", application of B.M.A. or of L-S.A. greatly reduced Scab-infection on the fruits, B.M.A. showing to better advantage than L-S.A., as where the counting method was used. It will be recalled that wet weather in May, 1930, favoured early infection. The pre-blossom application proved its worth in checking this, and, as subsequent conditions at East Malling were not so favourable to Scab-development, the effect of the "pink-bud" application was prolonged.

TABLE II.

Relative Area of Scab (by " category " method), and Percentage of Infected Fruits in those Picked (1930).

(*Variety—Cox's Orange Pippin.*)

Stock.	No. and Time of Spray-applications.	Average total number picked per tree.			Average " Scab-equivalent " per tree.			Average percentage of picked fruits with Scab per tree.		
		B.M.A.	L-S.A.	A.	B.M.A.	L-S.A.	A.	B.M.A.	L-S.A.	A.
I.	One pre-blossom (" pink-bud ") ..	70	201	89	3	7	22	20	40	77
II.		83	164	117	3	8	16	27	52	76
IX.		94	121	102	2	5	18	18	32	81
XVI.		60	68	20	5	7	25	29	36	68
V.	Two post-blossom	66	76	60	2	5	16	16	30	85
XIII.		82	73	88	3	3	15	16	21	65
III.	One pre- and two post-blossom ..	63	164	146	0	1	16	0	8	71
IV.		67	164	75	1	1	10	4	9	55
		L-S.G.	C.S.G.	G.	L-S.G.	C.S.G.	G.	L-S.G.	C.S.G.	G.
VI.	Two post-blossom	28	53	64	2	4	20	24	28	61
X.		51	40	65	5	6	21	34	46	78

Post-blossom sprays, aided by better weather in June, checked further development of existing infections, and ultimately showed control approximately equal to that given by a pre-blossom application.

Both very weak L-S. (1-150) G. and C.S. (0·4 per cent) G. markedly reduced infection. Cumulative effect of these sprays seems evident now (for the same trees have received the same sprays every year), which strengthens an opinion, expressed elsewhere (1), that weaker sprays such as these would be valuable if used after lime-sulphur (1-30) applied at "pink-bud". Such a procedure might help to solve the problem of post-blossom spray-injury. This possibility will be explored in future field experiments.

(*c*) *Percentage of Infected Fruits in those Dropped.*

It has already been stated that, where no pre-blossom application was made, comparison between the percentages of infected fruits picked, and dropped, showed lack of *early* Scab-control. This is wholly supported by the figures in Table III showing the proportion of Scab-infected fruits among those dropped.

TABLE III.

Percentage of Infected Fruits in those Dropped (1930).

(*Variety—Cox's Orange Pippin.*)

Stock.	No. and Time of Spray-applications.	Average total number dropped per tree.			Average percentage of dropped fruits with Scab per tree.		
		B.M.A.	L-S.A.	A.	B.M.A.	L-S.A.	A.
I.	One pre-blossom ("pink-bud") ..	55	196	124	8	18	52
II.		166	223	254	14	19	50
IX.		61	72	133	5	16	45
XVI.		63	109	77	10	20	64
V.	Two post-blossom ..	82	373	239	20	20	61
XIII.		86	235	214	18	21	46
XV.	One pre- and two post-blossom	18	97	97	–	3	19
III.		40	276	225	4	4	43
IV.		59	210	154	3	7	37
		L-S.G.	C.S.G.	G.	L-S.G.	C.S.G.	G.
VI.	Two post-blossom ..	109	94	81	20	20	47
X.		198	129	93	20	32	52

It will be seen that, in the controls, a much greater percentage of the dropped fruits was infected than in trees sprayed, pre-blossom only, with B.M.A. or L-S.A. This indirectly shows that the single spray adequately protected the very small fruits; also that Scab, unchecked, is responsible for appreciable loss of crop in seasons favourable to early Scab-development. There was a smaller proportion of dropped, as well as picked fruits, infected, with B.M.A. than with L-S.A. This supports other data which show that B.M. (8-8-100) A. was rather more effective, pre-blossom, than L-S. (1-30) A.

With B.M.A., the percentage of dropped fruits, infected, was greater after only post-blossom than after only pre-blossom application. The disease evidently attacked the small fruitlets before post-blossom sprays were applied, and this resulted in slight loss of crop. With L-S.A., post-blossom, fruit-drop (spray-damage) had the effect of lowering the *percentage* of dropped fruits infected by reason of the increased number of dropped fruits *not* infected. Hence, this percentage was not significantly greater than where only a " pink-bud " application was made.

With three applications, one pre- and two post-blossom, the young fruitlets were so efficiently protected that the proportion infected among those dropped was very small (approx. 4·0 per cent). On the other hand, the proportion in the controls was moderately large (approx. 40·0 per cent).

(*d*) *Percentage of Infected Fruits in those Picked.*

A glance at the last three columns in Table II shows that, with this method of assessing results, as with the " category " method, B.M.A. was fungicidally superior to L-S.A. Considered generally, results from the two methods are similar, but, in particular, certain issues tend to be masked where the results are based solely on percentages. For example the efficiency of the sprays is prejudiced by the counting method, for the difference between sprayed trees and controls is greater where figures are based on Scab-areas. In other words, a percentage of scabbed apples from controls represents, in fact, much greater infection than the same percentage from sprayed trees, on account of the larger size of the infection-spots.

It seems desirable, therefore, to base results of trials such as these not only on numerical counts, but also on some system whereby the scabbed areas on the fruits are graded, for the one without the other may be misleading. Similarly, it can be shown that severe Scab-infection is, itself, sufficient to reduce fruit-size, and therefore weight, to some extent. Hence, comparison between only the weights of scabbed and of " clean " fruits is also open to criticism.

(*e*) *Survey of Scab-infection on Leaves.*

This survey was made on July 14th and 15th, 1930, nearly a month after the second post-blossom application. It showed that both B.M.A. and L-S.A., at " pink-bud ", gave moderately good leaf-protection during the earlier part of the season, B.M.A. being rather more efficient than L-S.A.

TABLE IV.

Scab-infection on the Leaves (1930) (*by " category " method*).

(*Variety—Cox's Orange Pippin.*)

Stock.	No. and Time of Spray-applications.	Average " Scab-equivalent " per tree.		
		B.M.A.	L-S.A.	A.
I.	One pre-blossom (" pink-bud ")	1·4	2·0	4·5
II.		1·8	2·2	4·0
IX.		1·2	1·6	4·0
XVI.		1·4	1·0	4·7
V.	Two post-blossom	0·6	1·2	4·3
XIII.		1·2	0·8	3·8
XV.	One pre- and two post-blossom	0·0	0·0	1·5
III.		0·0	0·0	3·3
IV.		0·0	0·0	2·5
		L-S.G.	C.S.G.	G.
VI.	Two post-blossom	1·8	1·6	4·2
X.		1·8	3·0	4·4

Two post-blossom applications gave good control, while three applications reduced Scab-infection to zero, as with the fruits.

Lime-sulphur (1-150) and colloidal sulphur (0·4 per cent), post-blossom, each with gelatine (0·1 per cent) as " spreader ", gave some control, but neither was as effective as lime-sulphur (1-100) or Bordeaux mixture (8-25-100), post-blossom.

Leaf-infection was most prevalent on the East and North sides of many trees, controls especially. Similar lack of uniformity in distribution of leaf-infection has been observed on these trees in former seasons. A possible explanation of this is that the trees dry more quickly on the South-West than on the North-East in the spring and early summer months.

(*f*) *A Dusting Experiment.*

In addition to the main spraying tests discussed above, a trial of sulphur dusts was arranged and carried out on a neighbouring farm in continuation of preliminary tests made in 1929 (2). Bush trees of the apple varieties Belle de Boskoop (30 trees), Ribston Pippin (30 trees) and Cox's Orange Pippin (27 trees), all " worked " on a dwarfing rootstock, were placed at the writer's disposal.

In spite of elaborate planning of the trial and application of the dusts, results in Scab-control were inconclusive, for all trees were so severely attacked by Leaf-eating Weevil, Winter-Moth Caterpillar and Apple-Blossom Weevil that the crop was very irregular. Cox's Orange Pippin and Ribston Pippin suffered no apparent damage as a result of the treatments, but Belle de Boskoop developed leaf-drop sufficiently to prejudice future cropping, thus confirming observations made on this variety during the previous year (2). Some aspects of Scab-control by dusting have been more fully dealt with elsewhere (4).

II. CONTROL OF BROWN ROT (*Sclerotinia fructigena*).

(*Variety—Cox's Orange Pippin.*)

Records concerning this disease were incidental, being made concurrently with Scab-grading. Brown Rot-infections were fairly common on these fruits in 1930, but as these experiments have provided no similar data previously, any inferences drawn must be regarded as tentative.

TABLE V.

Brown Rot-infection on Picked Fruits (1930).

(*Variety—Cox's Orange Pippin.*)

Stock.	No. and Time of Spray-applications.	Average number " Primary "* infections per tree.		
		B.M.A.	L-S.A.	A.
I.	One pre-blossom (" pink-bud ") ..	7	3	6
II.		8	4	11
IX.		7	3	7
XVI.		4	1	8
V.	Two post-blossom	2	3	8
XIII.		3	2	3
XV.	One pre- and two post-blossom ..	–	–	4
III.		7	0	4
IV.		10	2	8
		L-S.G.	C.S.G.	G.
VI.	Two post-blossom	5	5	12
X.		3	5	9

* For explanation see text.

The figures reveal certain points also suggested by general observation. Scabbed fruits were much more prone to infection than " clean " ones, and certain fruits showed that the Brown Rot fungus had made convenient entry through cracks due to Scab-infection. Brown Rot also occurred where Apple Sawfly larvae had attacked the fruits.

Fruits from control trees on stocks (Nos. XV, XIII and III) imparting some resistance to Scab in this variety (2), also showed less tendency for Brown Rot-infection. On Nos. IV, VI and X stocks, trees were not sprayed with lead-arsenate, so that additional points of entry for Brown Rot resulted from indifferent insect-control. Indeed, more fruit-infection was recorded on trees on these stocks than on those comparably sprayed with lead-arsenate.

Most fruits sprayed *pre-blossom* with Bordeaux mixture were severely russeted *and cracked*. Brown Rot was commonly found on such fruits, the fungus evidently having obtained entry through the cracks. Where trees were sprayed with Bordeaux mixture *post-blossom* only, the fruits were severely russeted but seldom cracked, and Brown Rot here was comparatively rare.

L-S.A.-sprayed fruits were not seriously blemished as a rule, especially where three applications were made, and Brown Rot among these was not common.

It can be stated with some degree of confidence, therefore, that routine spraying for Scab-control indirectly helps to control Brown Rot (*Sclerotinia fructigena*) of the fruit. The suppression of any agents that cause skin-blemishes (other than very superficial ones, such as russeting) automatically checks loss due to this fungus.

A very large number of " contact " infections developed while the fruits were temporarily being stored in an oasthouse to await Scab-grading. These occurred plentifully on healthy fruits in contact with rotted ones in the storage boxes. Such infections can wholly be prevented by the removal and destruction of all rotted fruits prior to storage, even when such is intended to be of only short duration. Attention has already been drawn to this by Wormald (5).

III. CONTROL OF APPLE SAWFLY (*Hoplocampa testudinea*).

(*Variety—Cox's Orange Pippin.*)

Records of Sawfly-attack on the 1930 crop from these trees were necessarily made in connection with fruit-drop, and examination of them revealed a few points of more than passing interest. The data, which show that there was better control of this pest by a fungicide with lead-arsenate than by lead-arsenate alone, will be presented elsewhere when further observations have been made.

IV. ROOTSTOCK INFLUENCE ON INFECTION BY APPLE SCAB.

(*Variety—Cox's Orange Pippin.*)

It has already been stated that control trees showed fruit-russet and cracking more commonly on No. IX rootstock than on any other. Rootstock influence (based on *control* trees only) on Scab-infection, also, was again evident in 1930 (see Table I). In general, the results of observations on the fruits conform with those (on shoots and leaves) already published (2). Control trees on Nos. XVI, V, I, X and IX gave more heavily-infected fruits than those on Nos. XV, IV, XIII and III. Those on Nos. VI and II occupied an intermediate position. This general classification for the one year is based on the percentage of apples infected in the entire crop, dropped and picked.

Leaf-infection also revealed the influence of rootstock as in previous years (see Table IV). Control trees on Nos. XVI, I, X, V, and VI showed greater susceptibility than those on Nos. XIII, III, IV and XV. Those on Nos. IX and II occupied an intermediate position.

Thus, there was marked similarity in results on leaves and fruits in 1930. Stock No. X induced greater relative susceptibility on fruits and leaves in 1930 than on leaves and shoots in previous years. Apart from such seasonal variation in the reaction of individual rootstocks, however, there is now clear evidence that, inherently, certain layered rootstocks induce greater Scab-susceptibility than others in Cox's Orange Pippin.

V. SUMMARY AND CONCLUSIONS IN REGARD TO APPLE SCAB.

A fourth year's investigation, in 1930, of the incidence and control of this disease at East Malling is described, and the results are tabulated and discussed, with frequent reference to those (already published) obtained during the first three years.

Spraying experiments. A detailed discussion of the results obtained on Cox's Orange Pippin is preceded by certain general remarks on weather conditions during the year.

The trees bore their first good crop in 1930, and special efforts were made to collect as many data as possible on the fruits at the expense of those on leaves and shoots, which had been the primary sources of results in the earlier years. The *picked* crop was Scab-graded, and all *dropped* fruits were counted and graded for Scab and Sawfly. By employing such different methods of approach to the same end, completeness of data was ensured. The results, in the main, confirmed previous findings. Although Bordeaux mixture proved the best " scabicide ", it showed certain economic disadvantages, especially the tendency to cause spray-injury (for instance, leaf-burn, defoliation, fruit-russeting and indirect crop-reduction by damage to blossoms and by severe leaf-injury in former years) and its inefficacy against Red Spider and Apple Mildew. Lime-sulphur gave very good control of Apple Scab, Mildew and Red Spider, especially when applied three times, once before and twice after blossoming. It caused fruit-drop when used, post-blossom only, at 1-100. Previous data obtained in these trials have not shown a similar result. In spite of fruit-drop, these trees did not suffer reduction in picked crop below that on comparable Bordeaux-sprayed or control trees. Where a pre-blossom lime-sulphur spray was used with or without post-blossom applications, much greater crops were picked than from any other, comparable trees, as in previous years.

The importance of the "pink-bud" application, especially when severe infection occurs early in the season, as in 1930, was again emphasized.

Influence of Rootstock. It is shown that, in the main, certain rootstocks promote greater Scab-susceptibility than others in Cox's Orange Pippin, but that such influence is governed, to some extent, by seasonal conditions.

A few incidental observations were made on the control of Brown Rot (*Sclerotinia fructigena*) of the fruits and on that of Apple Sawfly (*Hoplocampa testudinea*).

PART V.

I. CONTROL OF APPLE MILDEW.

(*Variety—Cox's Orange Pippin.*)

Results in 1929.

Records of Mildew-infection were made as part of the scope of the main spraying experiments on this variety. Results obtained in 1926, 1927 and 1928 have already been published (2). The number of infections on the 1929 prunings was added to that of infections appearing on the same trees at bud-break in spring 1930. The latter were not cut out in order that any cumulative effect of spraying might be preserved.

The results are arranged in Table VI, the *total* number of Mildew-infections being expressed as a percentage of the number of pruned shoots.

TABLE VI.

Mildew-infection on Young Shoots (1929 *and* 1930).

(*Variety—Cox's Orange Pippin.*)

Stock.	No. and Time of Spray-applications.	Average percentage Mildewed shoots per tree (1929).			Average percentage Mildewed shoots per tree (1930).		
		B.M.A.	L-S.A.	A.	B.M.A.	L-S.A.	A.
I.	One pre-blossom ("pink-bud") ..	34	26	42	33	29	59
II.		21	21	23	21	18	32
IX.		25	18	32	23	19	47
XVI.		15	19	21	9	13	12
V.	Two post-blossom ..	29	10	24	65	25	57
XIII.		27	7	22	36	13	28
XV.	One pre- and two post-blossom ..	12	7	13	7	7	11
III.		22	14	26	14	8	35
IV.		11	7	20	17	7	17
		L-S.G.	C.S.G.	G.	L-S.G.	C.S.G.	G.
VI.	Two post-blossom ..	14	22	30	20	29	29
X.		15	17	29	15	25	36

Little control was given by a " pink-bud " application of B.M.A. or of L-S.A., for only slight decrease of infection was evident in each case. Two post-blossom L-S.A. applications gave a much better result than one, pre-blossom, but B.M.A., post-blossom, was not effective. Three L-S.A. applications, one pre- and two post-blossom, gave similar results to two, post-blossom. There was little evidence of increase in the fungicidal value of L-S. against Mildew where lead-arsenate was omitted (2).

Both weak L-S. (1-150) G. and C.S. (0·4 per cent) G., applied twice, post-blossom, afforded some control. As in previous years, weak lime-sulphur was somewhat the better of the two, comparing very favourably with the less dilute spray (1-100) with arsenate but without gelatine.

Results in 1930.

The same procedure as described above was adopted for obtaining data on infection in 1930. All existing infections were removed in spring, 1931, when this particular experiment was concluded. The figures are arranged in Table VI.

Some control was given by B.M.A. and L-S.A., pre-blossom, on trees on stocks Nos. I, II and IX, but not on No. XVI. L-S.A. was slightly the more effective. Two post-blossom L-S.A. applications, by reducing infection by about one-half, gave similar control to the single, pre-blossom, spray. B.M.A., post-blossom only, was not effective ; indeed, as in 1929, infection was actually greater on trees sprayed post-blossom with B.M.A. than on controls. It will be recalled that post-blossom applications of B.M.A. (8-25-100) caused severe defoliation, and it is not unlikely that the fungus finds easier access to unprotected, young, axillary buds than to those well-covered by the bases of petioles.

Previous tests have not consistently shown that a single, pre-blossom, L-S.A. application was as effective as two, post-blossom, but they have indicated that although B.M.A., pre-blossom, reduced infection slightly, it was not effective post-blossom.

Three applications of L-S.A. and of L-S. were again most satisfactory, while B.M.A. (three times) also afforded some control, doubtless due, in the main, to the direct action of the pre-blossom spray in scorching up existing infections. Weak L-S. (1-150) G. applied twice, post-blossom, compared a little less favourably with L-S. (1-100) A. than in the previous year, but gave some control, and was rather more effective than C.S. (0·4 per cent) G.

(*Variety—Belle de Boskoop.*)

Results in 1929.

These results have already been published (2), but the paper went to press before infections appearing at bud-break in 1930 had been recorded. Now that the number of these has been added to that of infections on the 1929 prunings, it is desirable to modify a statement appearing on page 287 of the previous published results, as follows :—" the slight infection on all trees in 1929 suggests that the seasonal factor was the most important one leading to the discrepancy in results shown by the same set of trees in the two years." (i.e. 1928 and 1929.)

The revised results, based on the *total* number of 1929 Mildew-infections (see Table VII), show no discrepancies such as existed in the table of figures on page 286 (2). For example, liver of sulphur, though not effective in 1928, appeared to have given control in 1929, but in the revised figures presented herewith, the result conforms with that in 1928.

TABLE VII.

Mildew-infection on Young Shoots (1929 *and* 1930).

(*Variety—Belle de Boskoop.*)

Post-blossom Spray-Treatment.	Total No. Infections per ten trees.*	Total picked crop on ten trees.	Average " Russeting-equivalent "† per tree.	Total No. Infections per ten trees.
	1929.	1930.	1930.	1930.
1. L-S. (1–100) +G. (0·1%)	79	706	24	94
2. C.S. (0·4%) +G. (0·1%)	114	1,266	20	155
3. A.P.S. (1–200) +G. (0·1%)	235	—	—	—
4. Liv. of S. (0·3%) +G. (0·1%)	220	—	—	—
5. Proprietary S. Spray (1·0%) +G. (0·1%) ..	203	—	—	—
6. Soda-Soap Solution (20–10–100)	71	1,184	21	115
7. White-oil Emulsion (1·0%) +G. (0·1%) ..	159	915	19	132
8. Flowers of Sulphur ..	159	—	—	—
9. Sulphur-Dust	143	1,145	19	99
10. Gelatine-sprayed controls	242	1,064	24	151

* Revised figures for 1929 infection. They supersede those published in *Journ. Pom. & Hort. Sci.* (1930), 8, p. 286, which were incomplete.

† Figures not comparable with those for 1929 crop as they were obtained by a different method. They are relative only amongst themselves.

Infection was very severe on this variety in the dry 1929 season. Soda-soap solution and lime-sulphur, respectively, gave the best Mildew-control ; both colloidal sulphur and sulphur-dust afforded moderate control ; flowers of sulphur and white-oil emulsion were of little value, while ammonium polysulphide, liver of sulphur and the proprietary sulphur spray were not satisfactory. Colloidal sulphur was effective in 1929 but not in 1928. Apart from this, the results obtained in the two years were corroborative.

Results in 1930.

A third year's tests were made in 1930. Subsequently, the experiment was discontinued, for the trees had grown too big to be given the necessary attention in the time available.

In order to simplify the experiment, and to reduce the labour involved, it was decided to omit, in 1930, those sprays which, previously, had shown little or no promise. Five, therefore, were included in the 1930 tests, with the same control trees. Ten trees were sprayed with each specific, and in every case trees received the same sprays as in 1929 and 1928.

Two post-blossom applications were made, the first at petal-fall, and the second about three weeks later. The figures set out in Table VII represent the average number of infections per tree (including those that appeared at bud-break in 1931). They show that lime-sulphur and sulphur-dust gave the most effective Mildew-control, while white-oil emulsion and colloidal sulphur were unsatisfactory. Soda-soap solution, which gave the best results in 1928 and in 1929, was hardly as effective in 1930.

With regard to spray-injury, none of the sprays caused fruit-russeting, fruits from gelatine-sprayed controls being the most russeted. Soda-soap solution burnt the young shoot-tips, as formerly. Fruits sprayed with white-oil emulsion, and those dusted with sulphur, again showed less russeting than those from controls, as in 1929. Soda-soap solution, which caused such pronounced fruit-drop in 1929, caused none in 1930; indeed, there were greater crops on these trees than on controls. Taken with the fact that this spray caused no fruit-russeting either, the indication is that the result was influenced by seasonal conditions. As the spray is readily soluble and primarily intended for direct and rapid action, results would probably show the effects of dilution of the spray-deposit by rain more than those from insoluble and, hence, more lasting specifics. Its " performance " might thus depend very largely on the type of season in which it was used. This spray, also, was less fungicidally effective than in the previous two seasons. Apparently, therefore, its propensity for causing spray-damage varied directly as its fungicidal value.

Both lime-sulphur and white-oil emulsion (especially the former) caused fruit-drop, as in 1929. While colloidal sulphur and sulphur-dust caused like damage in 1929, they gave none in 1930; in fact, as with soda-soap solution, slightly larger crops were gathered from treated than from control trees.

II. ROOTSTOCK INFLUENCE ON INFECTION BY APPLE MILDEW.

(*Variety—Cox's Orange Pippin.*)

Results in 1929.

Rootstock influence on Apple Mildew was assessed, as before, on *control* trees only. Results are seen in Table VI. Trees on No. I stock were again specially susceptible, while those on Nos. XVI, IV and XV again showed much more resistance. No. II induced, relatively, much less infection than formerly, and occupied an intermediate position together with Nos. III, V, VI, IX and X.

Results in 1930.

Trees on No. I and No. V stocks were much more heavily infected than others, while those on Nos. XVI, IV and XV were lightly infected by comparison, as in 1929. No. V induced, relatively, much more infection than formerly, while Nos. II, III, VI, IX and X again occupied intermediate positions. No. XIII showed a tendency, in both seasons, to induce resistance.

III. SUMMARY AND CONCLUSIONS IN REGARD TO APPLE MILDEW.

The results of spraying for Mildew-control on Cox's Orange Pippin and Belle de Boskoop in 1929 and 1930 are discussed. Lime-sulphur was shown to be the most effective spray of those tested on the former variety, Bordeaux mixture and colloidal sulphur proving rather unsatisfactory. Weak lime-sulphur (1-150) with gelatine (0·1 per cent) compared favourably with the stronger spray (1-100) with arsenate (0·4 per cent) but without gelatine, when applied twice, post-blossom.

On Belle de Boskoop, soda-soap solution (20-10-100), lime-sulphur (1-100) and a sulphur-dust, respectively, gave the best results. All were applied twice, post-blossom. Soda-soap solution was harmful in 1929, and lime-sulphur in both years proved unsafe, each spray causing fruit-drop. Sulphur-dust should be used with caution, as it was of doubtful safety in 1929, although no damage resulted in 1930. Colloidal sulphur (0·4 per cent) with gelatine (0·1 per cent) was not satisfactory.

Previous evidence in these trials of the influence of rootstock on Mildew-susceptibility was confirmed in 1929 and 1930. Cox's Orange Pippin trees on No. I stock were pre-eminently susceptible, while those on Nos. XVI, IV and XV were resistant.

PART VI.

I. SPRAY-INJURY.

(*Variety—Cox's Orange Pippin.*)

It was pointed out in the account of experiments made in previous years (2) that " the effect of the sprays in controlling Scab and Mildew must of course be taken in conjunction with any spray-injury caused, if the true practical value of the different fungicides is to be appraised."

The problem that arises over the successful use of fungicides is a difficult one, for the concentration of spray used must be adjusted to provide maximum disease-control with a minimum of injury. Naturally, it would be easy to control Apple

Scab with lime-sulphur or with Bordeaux mixture by using these sprays at high concentrations, but, in practice, it is found that the stronger the spray, the greater the damage. Obviously, it would not be economically advisable to control Scab at the risk of seriously damaging the trees, so that the formula for a " safe " spray must be sought. This often entails a reduction in strength of certain fungicides—lime-sulphur, for example—for use post-blossom, when damage from this spray seems most likely to occur. It is unfortunately true that the degree of spray-injury caused by any one fungicide varies considerably from season to season, depending on weather conditions. Furthermore, even local conditions and cultural practice appear to exert an important influence on the results of spray treatment, so that, clearly, it is undesirable to regard the results obtained in any one season or in any one locality as final.

In Parts IV and V of this paper, the discussion of results dealt mainly with the value of different fungicides for Scab- and Mildew-control, while spray-injury was but little considered. The results discussed below are chiefly concerned with the effect of the sprays on the trees.

(*a*) *Total Fruit-drop* (*by counting*).

It will be recalled that the number of dropped fruitlets was recorded periodically after petal-fall. The figures obtained for each tree were totalled at the end of the season and averaged for similarly-treated trees. These averages are set out in Table III. In conjunction with the records of fruit picked (see Table II), they show that L-S.A. caused fruit-drop when applied post-blossom, but not pre-blossom. That conclusion is supported by the figures obtained by sampling. In this method, representative branches on each tree were selected at blossom-time and labelled. As soon as the fruit had " set ", the number on these branches was recorded. When all fruit-drop had ceased, the number of fruits was again recorded. The difference between the two sets of figures gave a measure of the fruit-drop from similarly treated trees. *When due allowance was made for loss of crop due to Scab on the controls,* it was evident that L-S.A., post-blossom, had caused fruit-drop (see Table VIII).

Post-blossom applications of L-S. (1-150) G. and C.S. (0·4 per cent) G. also appear to have caused slight fruit-drop.

The result is specially noteworthy by being new to these investigations. Judged by results obtained in former seasons, lime-sulphur was regarded as " safe " on Cox's Orange Pippin when applied, post-blossom, at 1-100. Although such detailed cropping records as these have not previously been made in these trials, general observations in the field, together with the available data, have supported this claim. The present result, therefore, either reflects seasonal influence or indicates that fruit-drop has previously occurred without being apparent in the available records. That the effect was seasonal received support

TABLE VIII.

Estimated Percentage Fruit-drop (1930) *by sampling, based on Number of Blossoms Fertilized.*

(*Variety—Cox's Orange Pippin.*)

Stock.	No. and Time of Spray-applications.	Average percentage Fruit-drop per tree.		
		B.M.A.	L-S.A.	A.
I.	One pre-blossom (" pink-bud ")	71	64	80
II.		71	57	77
IX.		66	45	77
XVI.		66	72	86
V.	Two post-blossom	74	85	92
XIII.		53	88	80
XV.	One pre- and two post-blossom	47	97	78
III.		50	73	68
IV.		65	58	73
		L-S.G.	C.S.G.	G.
VI.	Two post-blossom	85	84	74
X.		86	79	74

during a general inspection of the plot while the fruitlets were still on the ground, for such definite distribution of fruit-drop as was then seen had not been observed in the earlier years of the experiment.

Nevertheless, it will be recalled that lime-sulphur was applied, post-blossom, when the sky was overcast, for it is generally assumed, from circumstantial evidence, that greater injury is likely to accrue where this spray is applied in hot sunshine. Yet it must not be forgotten that a different spraying machine from that previously employed was used in 1930. The delivery pressure (200-220 lb. per sq. inch) was much greater than before, but it is still open to question whether delivery pressure really governs spray-injury to any extent.

(*b*) *Total Crop Picked.*

The data are classified in Table II. In these experiments, trees sprayed with lime-sulphur have consistently borne much greater crops than others. It will be observed that, in 1930, L-S.A.-sprayed trees again bore the heaviest crops, in the aggregate, except where only post-blossom applications were made, for in this case the numbers are equal. Thus, although L-S.A., post-blossom, caused fruit-drop, it did not reduce the total picked crop below that on control trees and on those Bordeaux-sprayed. However, when due allowance is made for other factors, the effect of some loss of crop really can be seen. Bordeaux-injury has previously been revealed as a reduction in crop ;* so has Scab-injury on the control trees. Discounting any stimulating effect of L-S.A., as well as any depressing effect (e.g. fruit-drop) on the crop, it is therefore to be expected that L-S.A.-sprayed trees would crop rather more heavily than the others. This actually has occurred in previous years, when the increase was so great that it even suggested stimulation by the spray.

There is slight evidence that a pre-blossom application of lime-sulphur mitigated fruit-drop, but it is difficult to be certain whether this was due to prevention of " sulphur-shock " or to better Scab-control on the fruitlets than where only post-blossom applications were made. The figures showing the percentage of infected fruits in those dropped (see Table III) suggest that the latter explanation is valid, but possibly incomplete. Certain data collected in 1928 in regard to leaf-burn (spray-injury) suggested that " sulphur-shock " from post-blossom applications alone was mitigated by a pre-blossom spray (2).

These data also suggest that both L-S. (1-150) G. and C. S. (0·4 per cent) G., post-blossom, caused slight loss of crop.

(*c*) *Blossom-Trusses.*

TABLE IX.

Blossom Trusses (1930).

(*Variety—Cox's Orange Pippin.*)

Stock.	No. and Time of Spray-applications.	Average No. Blossom-trusses per tree.		
		B.M.A.	L-S.A.	A.
I.	One pre-blossom (" pink-bud ") ..	328	310	326
II.		326	286	357
IX.		192	140	218
XVI.		184	150	133
V.	Two post-blossom	270	316	316
XIII.		259	304	331
XV.	One pre- and two post-blossom ..	91	154	177
III.		173	246	313
IV.		266	258	271
		L-S.G.	C.S.G.	G.
VI.	Two post-blossom	263	272	289
X.		307	275	352

The data set out in Table IX show that severe leaf-injury caused by post-blossom applications of B.M.A. in 1929 was reflected in appreciable reduction in the number of blossom-trusses produced in 1930. None of the other sprays

* Pre-blossom applications damaged the blossoms and so impaired cropping, while post-blossom applications reduced the number of blossom-trusses produced in the succeeding year by weakening the trees through severe leaf-burn and defoliation (2).

used caused similar injury. In certain instances, the controls blossomed more freely than trees sprayed with L-S.A., but when it is recalled that the latter have consistently borne heavier crops, it must be expected that some such effect ultimately would be apparent. In spite of freer blossoming, the controls, on the whole, gave much lighter crops, a fact that is largely attributable to Scab-injury.

(*d*) *Leaf-burn and Defoliation.*

Severe leaf-spotting and defoliation were again caused by B.M.A. applied post-blossom. This spray at 8-8-100, pre-blossom, and 8-25-100, post-blossom, is evidently quite unsuitable for Cox's Orange Pippin. The possibility of preserving adequate fungicidal properties while obviating the harmful nature of Bordeaux mixture, by reducing the concentration of copper sulphate, will form the basis of future field experiments with this spray. No appreciable damage was caused by any other spray, although L-S. (1-30) A., pre-blossom, caused marginal scorching of the earliest-formed leaves.* Indeed, where three applications of L-S.A. were made, the increased luxuriance of the foliage and the excellent " finish " (skin-quality) of the fruits were very noticeable.

(*e*) *Fruit-Russeting.*

TABLE X.

Russeting on Picked Fruits (1930) (*by " category " method*).

(*Variety—Cox's Orange Pippin.*)

Stock.	No. and Time of Spray-applications.	Average " Russeting-equivalent " per tree.		
		B.M.A.	L-S.A.	A.
I.	One pre-blossom (" pink-bud ")	21	4	7
II.		17	5	6
IX.		30	9	12
XVI.		13	3	4
V.	Two post-blossom	14	6	7
XIII.		12	6	7
XV.	One pre- and two post-blossom	—	—	8
III.		23	3	6
IV.		20	6	6
VI.	Two post-blossom	7	6	7
X.		7	6	6

Note.—Only Bordeaux-sprayed trees, and control trees on No. IX stock showed more than a negligible number of fruits on which the russeting might be regarded as a blemish.

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* Since the time of writing, the writer has received a paper by W. C. Dutton entitled " Spray-Injury " (Michigan State Coll. Agri. Exper. Sta., Special Bull. No. 218) in which certain observations on Bordeaux- and lime-sulphur-injury are recorded in great detail, supplemented by coloured plates. Many of the observations therein recorded closely parallel those made by the present writer during the course of these experiments.

The figures in Table X show that, as in previous years, B.M.A. caused fruit-russeting on Cox's Orange Pippin when applied pre- or post-blossom. More severe injury resulted from a "pink-bud" application (many fruits showed extensive cracking) than from post-blossom sprays (most fruits showed surface-russeting with little cracking). The omission of lead-arsenate (on trees on No. IV stock) was not accompanied by a reduction in damage. L-S.A., L-S.G. and C.S.G. caused no fruit-blemish.

Control trees (arsenate-sprayed) showed, on the whole, more russeting than those L-S.A.-sprayed, especially on No. IX rootstock. Russeting of fruit on control trees must be attributed to causes other than spraying. Reference has previously been made to this elsewhere (3).

II. Summary and Conclusions in Regard to Spray-Injury.

These cannot conveniently be divorced from disease-control, hence the main conclusions will be found in Part IV (V) "Summary and Conclusions in Regard to Apple Scab" (p. 284).

ACKNOWLEDGMENTS.

The writer acknowledges with gratitude the helpful criticisms of Mr. R. G. Hatton, Dr. H. Wormald and Dr. G. H. Pethybridge in the preparation of this paper.

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(*Received* 10/11/32.)

THE CONTINUITY OF HIGH AND LOW YIELDING TENDENCIES IN CITRUS TREES.

By H. CLARK POWELL.
Professor of Horticulture, University of Pretoria, South Africa.

In an effort to throw some light on the fertilizer requirements of bearing orange and grapefruit trees in the Eastern Cape Province, South Africa, numerous fertilizer plots have been laid down in several bearing groves in the Sundays River Valley. The system of plot selection has been based to a considerable extent on the system followed at the Citrus Experiment Station, Riverside, California.*

Groves were selected, among other things, for comparative uniformity of trees and soil and the availability of records of individual tree yields for several years previous to the commencement of the work. Each treatment was repeated five times on plots containing five trees in the smaller orchards and ten trees in the largest orchard. Thus each different treatment would be given to twenty-five to fifty trees, depending on the size of the orchard.

Through using the previous tree yield records it was possible to select the five plots receiving one treatment in such a way that the yield of the trees for the years immediately preceding the fertilizer treatment was approximately the same as the yield of the trees receiving any other treatment. Thus, in a given grove, Treatment 1 was given to twenty-five trees which had yielded approximately the same quantity of fruit for three years as the twenty-five trees in each of the other treatments. Any material differences in yield arising after the differential fertilizer treatments could be ascribed to the particular treatment, if it is true that low yielding trees remain low yielding on the average and high yielding trees remain high yielding.

In one Marsh grapefruit grove, planted in 1918, eight different fertilizer treatments were given, including a group of plots used as checks and which were given no fertilizer. Each treatment was given to five plots each containing ten trees, thus each treatment was applied to fifty trees. The yield of each group of fifty trees for the four years previous to the fertilizer applications was very similar, as can be seen from Table I.

The average yield of trees for each treatment has been very similar for the four years before the experiment. As each treatment is given to five plots, there will necessarily be high, medium and low yielding plots under each treatment. One example showing this can be given with the figures in Table II.

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* " Studies Preliminary to the Establishment of a Series of Fertilizer Trials in a Bearing Citrus Grove", L. D. Batchelor, E. R. Parker, Robert McBride. *Univ. Calif. Agric. Expt. Sta. Bul.* 451, April 1928.

TABLE I.

Previous Yields of Trees Under each Treatment.

Treatment.	Trees.	Total Yield for 4 years.	Average Yield per Tree.
		Field Boxes.	Field Boxes.
1	44*	1298·50	29·51
2	48	1364·75	28·43
3	43	1310·50	30·45
4	43	1327·50	30·87
5	43	1278·50	29·73
6	43	1312·75	30·52
7	46	1343·00	29·19
8	41	1272·75	31·04

* Certain young replants are not included in the records.

TABLE II.

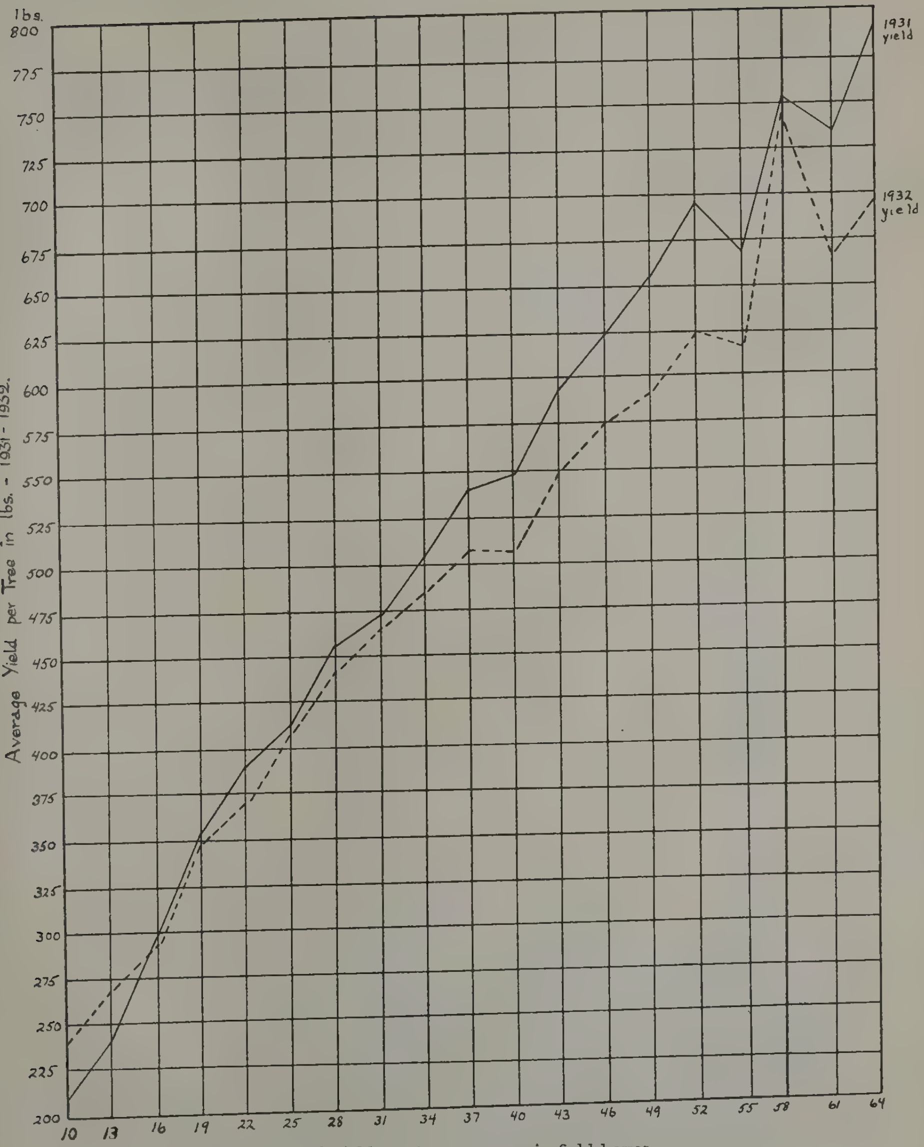
Yields of Individual Plots under Treatment 2.

Plot.	Trees.	Total Yield for 4 years.	Average Yield per Tree.
		Field Boxes.	Field Boxes.
2A	10	240·50	24·05
2B	9	339·75	37·75
2C	9	170·00	18·88
2D	10	368·75	36·88
2E	10	245·75	24·58
Total	48	1364·75	28·43

The causes of the differences in yield in this grove are believed to be mainly (1) variation in soil texture and water relationships; (2) variations in soil fertility, and (3) root stock influences. As these causes remain more or less constant over a period of years, it is expected that the *relative* productivity of each plot will remain constant.

The fertilizer trials in question are field trials laid down in commercial groves and as such are subject to numerous limitations. For example, a large number of plots might be given uniform treatment in order to study the relative permanence of high and low yielding characteristics but the size of the grove (20 acres) does not make this possible and at the same time permit of the differential fertilizer treatments. The individual tree records for each treatment will undoubtedly give some indication as to whether trees do or do not maintain their relative yielding capacities.

The crop harvested the season following the first applications of fertilizers could not have been affected by the treatments as the fruit was set and half developed when the first applications were made. No effect has been seen during



Total yield per tree 1927-30, in field boxes.

CONSISTENCY OF HIGH AND LOW YIELDING TENDENCIES—GRAPE FRUIT.

the current season and these two year picking records have been used in an effort to determine the behaviour of the trees in relation to their yields during the four years previous to the commencement of treatment.

It can be seen from Table III that trees that were low yielding during the four years before the commencement of the work have remained low yielding and that high yielding trees have remained high yielding for the subsequent two years. No trees have been used in these figures that were not planted in 1918, when the grove was laid out.

TABLE III.

Relative Consistency of High and Low Yielding Tendencies.

Total Yield per Tree for 4 years previous to experiment.	No. of Trees.	Average Yield per Tree in lb.	
		1931.	1932.
Field Boxes.			
10·00 to 12·75	13	213·46	244·76
13·00 to 15·75	18	239·94	264·16
16·00 to 18·75	57	298·38	294·89
19·00 to 21·75	80	353·13	348·61
22·00 to 24·75	110	383·20	368·68
25·00 to 27·75	125	414·30	409·12
28·00 to 30·75	127	456·58	435·09
31·00 to 33·75	100	473·94	458·90
34·00 to 36·75	93	507·03	480·69
37·00 to 39·75	90	539·93	507·41
40·00 to 42·75	63	548·33	506·09
43·00 to 45·75	59	590·03	550·84
46·00 to 48·75	37	625·62	574·97
49·00 to 51·75	30	653·90	585·06
52·00 to 54·75	28	692·50	625·64
55·00 to 57·75	14	668·92	617·85
58·00 to 60·75	15	751·60	748·13
61·00 to 63·75	7	734·57	669·85
64·00 to 66·75	2	780·50	692·50
67·00 to 69·75	1	825·00	785·00
70·00 to 72·75	1	630·00	406·00
	1070		

The figures given in Table III were based on a grove that can be considered as being approximately full bearing, the trees being 14 years old in 1932. In order to determine the value of records taken when trees are young, yield records for a Washington Navel orange grove planted in November 1923 were studied for the fifth, sixth and seventh years after planting.

This grove is also being used for fertilizer trials and as it contains only 400 trees, the plots have been restricted to ones of five trees each. As each treatment is replicated five times, twenty-five trees receive similar treatment.

The yield records on which the selection of the plots was based were taken in 1928, 1929 and 1930, when the trees were comparatively young.

Table IV.

Yield Records of a Young Orange Grove.

Total Yield per Tree for 3 years previous to experiment.		No. of Trees.	Average Yield per Tree in lb.	
			1931.	1932.
Field Boxes.				
1·25		1	97·00	87·00
3·00		1	75·00	74·00
3·75		1	40·00	45·00
4·00		2	89·50	108·00
4·75	A	3	161·00	155·33
5·00		3	165·33	155·33
5·25		5	158·80	163·40
5·50		7	139·42	130·57
5·75		8	143·25	188·00
6·00	B	10	175·80	181·90
6·25		10	174·70	164·20
6·50		12	162·41	179·66
6·75		19	161·73	167·84
7·00		16	148·87	159·43
7·25	C	14	187·07	203·64
7·50		18	185·33	188·61
7·75		22	179·63	186·91
8·00		20	177·15	195·05
8·25		22	194·18	199·59
8·50	D	25	192·95	202·29
8·75		23	204·30	210·34
9·00		16	190·18	200·62
9·25		8	200·25	208·25
9·50		17	208·35	217·35
9·75	E	12	225·08	236·08
10·00		18	219·72	226·27
10·25		11	228·54	238·18
10·50		16	235·81	245·37
10·75		10	222·70	229·00
11·00	F	3	244·33	265·00
11·25		5	226·80	242·80
11·50		5	233·40	236·00
11·75		2	223·33	216·00
12·00		1	276·00	305·00
12·25 to 14·00		14	272·92	261·42
Average of A Group		26	149·80	150·11
,, B ,,		67	162·82	169·50
,, C ,,		96	184·60	194·27
,, D ,,		88	199·05	207·54
,, E ,,		67	226·41	234·95
,, F ,,		16	235·43	247·43

The picking records in Table IV for 1931 and 1932 (before the effect of any fertilizer treatment was evident) show that the trees have very closely maintained their relative position in regard to the quantity of fruit borne. It could not be expected that a tree that had produced 8·00 field boxes of fruit before the experiment would consistently yield 3½ per cent more fruit each year than a tree that had borne 7·75 field boxes during the three years of records. If the trees are grouped as above in Table IV, however, it can be seen that they maintain their relative yield position very closely.

Although in this particular instance the use of yield records from trees that had not reached full bearing was apparently satisfactory, the use of records from older trees is advisable in cases where they are available. It should be pointed out that the factor of " alternate bearing " has not been evident in either of the two groves discussed above. This condition is far less common with citrus trees grown under suitable environment for the variety, than with deciduous fruit trees.

In Table III, the slight general reduction in yield for 1932 as compared with 1931 is due to climatic conditions.

(*Received* 15/11/32.)

NOTES ON SOME BACTERIAL PLANT DISEASES IN TASMANIA.

By W. J. DOWSON, M.A., D.Sc.

*Lecturer in Mycology, Cambridge University, late Plant Pathologist,
Department of Agriculture, Tasmania.*

During the course of a survey of plant diseases in the State of Tasmania, certain bacterial diseases of economic importance were recognized and examined but not investigated in any great detail. The four diseases noted here occur in some of the other States of the Commonwealth of Australia and in other parts of the world ; they are recorded here if only for the sake of extending our knowledge of the geographical distribution of bacterial plant diseases. One of them, halo blight of beans, formed the subject of correspondence between the Plant Pathologists of other Australian States and is still under investigation (1).

I. The Halo Blight of Beans (*Bacterium medicaginis var. phaseolicola* (Burkholder) Link & Hall).

In the rather wet spring of 1930, i.e. during October and November, several instances were noted of the failure of the commonest grown variety of dwarf bean, the Canadian Wonder, both in garden and field crops. Although to outward appearances the seed was sound, any discoloration being masked by the naturally dark testa, some plants never appeared above ground, and of those which did, a considerable number never got beyond the seedling stages and failed to produce more than the first pair of true leaves. These plants subsequently withered, and examination showed the growing points to be damaged. It was considered at first that the rows of beans had been severely damaged by birds ; but closer examination showed that this was not so. Bacterial lesions were present on the withering organs in the form of small water-soaked areas, turning reddish and of irregular shape. Under very moist conditions bacterial ooze was extruded from these spots.

Later on, as the surviving plants developed, similar lesions appeared on both leaves and stems, and finally the pods were attacked. The symptoms on such pods were characteristic and consisted of a few to numerous, circular, dark green (water-soaked) spots surrounding a paler centre. Again, under moist conditions, either in the open or under a damp bell jar, a whitish bacterial ooze was extruded from the centre of the spots. Affected plants finally withered away, the leaves being covered with rusty coloured dry spots and flecks. The appearance of rows of beans so affected was very marked and simulated severe scorching when seen at a little distance away.

Enquiry showed that infected plants had originated from seed imported from the neighbouring State of Victoria where the disease was devastating in severity during the same season. The Plant Pathologist of that State, Mr. D. B. Adam, had already commenced an extensive investigation of the trouble and there seems no reason to doubt the cause of the disease was *Bacterium medicaginis var. phaseolicola* which is carried in and on the seed (2). This being so, the writer at once took steps to find a source of disease-free seed for Tasmania, and the mainland being out of the question, enquiries were directed to Kenya Colony and New Zealand in both of which Canadian Wonder beans are extensively grown. Through the kindness of the New Zealand mycologist, Dr. G. H. Cunningham, Tasmania was able to procure a small quantity of certified disease-free seed in spite of the fact that the Dominion was short of seed owing to the existence of a similar, if not identical disease (3). By this means a nucleus was provided for raising disease-free seed for future use in Tasmania. The position on the mainland of Australia has been summarized recently by H. A. Pittman, Plant Pathologist for Western Australia (1).

II. BACTERIAL SPOT OF CAULIFLOWERS (*Bacterium maculicola* (McC.) McCulloch).

During the same wet season of 1930-31, when the bean blight was under investigation, another disease was brought to the author's notice, this time on half-grown cauliflowers. The Australian makes little or no distinction between cauliflowers and broccoli, the chief crops being ready for market in winter, i.e. June to August, having been planted six months previously.

In April and March 1931, i.e. autumn, several specimens were sent in for examination from both town and country gardens. The characteristic symptom was a spotting of the older leaves, the oldest and youngest being unaffected. The spotting took the form of numerous, minute, green to dark purple, irregularly shaped areas between and on the veins. Subsequently, many such spots would coalesce to produce large necrotic areas, almost black in colour, a sq. cm. or more in size, with straight outlines due to the veins. Such affected leaves turned prematurely yellow and the general effect upon the plants was a decided stunting with the production of small " heads."

Microscopic examination failed to indicate the likelihood of a fungus parasite being the cause of the disease and as pockets of bacteria were constantly found in both young and old spots, the disease was noted as being probably of bacterial origin. Isolation plates produced a white, Gram-negative, motile organism, generally corresponding with Miss McCulloch's bacterium (4), the cause of very similar symptoms in the United States. The chief difference so far noted is the absence of greening in cultures on nutrient agar and in Fermi's solution, which characterizes the American isolations. This, however, may be due to differences in the medium and of temperature, as pointed out by Miss Lacey (5).

It was noted at the time that the outbreak coincided with a spell of cold wet weather, a further point in agreement with the American disease.

As a temporary means of control spraying with Bordeaux mixture was resorted to and the spread of the trouble was certainly checked, although this may have been due more to an improvement in the weather than to the spraying. As the disease is seed borne (6), the further advice was given as to the desirability of either making sure that future seed supplies were obtained from places where the disease was unknown, or of disinfecting the seed on arrival with corrosive sublimate. Attention was also directed to three soil conditions notoriously prevalent in the State, viz. lack of adequate drainage, lime and available potash, which may have predisposed to the disease.

Subsequent work in England has shown that the organism isolated in Tasmania was capable of producing a spotting disease of young cauliflower plants under certain conditions. Thus, plants sprayed on the under side of the leaves with a watery suspension of the organism and kept under a bell jar in the open during the spring of 1932 were infected in about three weeks, the resulting spotting being similar to that recorded by E. F. Smith (4). A much more rapid result was obtained in the laboratory at room temperature when similar plants were treated in the same way and likewise kept moist under a bell jar. In this way far more extensive but less numerous lesions were obtained within seven to ten days.

III. WALNUT BLIGHT (*Bacterium juglandis* (Pierce) E. F. Smith).

Walnuts are not grown on a commercial scale in Tasmania, but are found in many town gardens, on most estates, and in orchards where they have been planted as outside rows of trees. In most of these situations, but not in all, the trees suffer badly from annual ravages caused by the blight organism recorded for the first time in the State by Rodway (7) in 1912.

All parts of the shoots may be attacked, the most conspicuous symptoms being numerous, minute, angular lesions on the leaves, including the veins and petioles. Characteristic large black spots occur on and in the fruits, which are ruined. The least obvious but most important lesions, from the point of view of carrying over the disease, are the small, elongated, black areas on the young shoots, many of which die back. It is from these that infection of the new leaves and fruits takes place in spring, especially during rain, as indicated by Wormald (8).

No control work has yet been attempted along the lines of using resistant varieties, and the only preventive measures so far adopted were undertaken on the author's advice by an orchardist in northern Tasmania. In this instance, after pruning out as much of the dead wood and infected shoots as was possible and manuring with sulphate of ammonia and superphosphate in early spring the trees were sprayed at the same time as the neighbouring apples and with the same strength fungicides. 6-4-40 Bordeaux mixture was applied at the " green tip " followed with 1-20 lime-sulphur at the " pink " stage of the apple blossoms. At the end of two seasons it was reported that the blight had been much reduced and that a good crop had been obtained at very little cost. Such treatment, satisfactory under these conditions, viz. proximity to apples which have to be sprayed in any case (for scab), might not prove so economical in a commercial way. But, for the time being and until the value of resistant types has been proved, this seems a commendable practice.

From typical specimens a Gram-negative organism with one polar flagellum was isolated which produced copious, moist, glistening growth, pale lemon yellow in colour, on steamed potato blocks, all of which characters agree with *B. juglandis*. It was not possible to try infection experiments in Tasmania but such will be attempted in the near future with the organism isolated in Tasmania.

IV. MULBERRY BLIGHT (*Bacterium mori*, Boyer & Lambert emend. E. F. Smith).

Mulberries in Tasmania are grown even more sparsely than walnuts but in recent years the demand for trees has increased and at the present time a large nursery at Hobart grows a considerable number. The trees are more common in gardens and orchards in the south of the State than in the north ; the blight disease was recorded from the nursery at Hobart and from an orchard in the Spreyton district of northern Tasmania. In both instances young trees were involved.

The infected areas of leaves and shoots are black and similar in appearance to those of the walnut blight except that the lesions are surrounded by a yellow halo and that the leaves are often much distorted. Also, like the walnut disease, the occurrence of the disease year after year is due to the lesions on the young shoots, but here they are even less conspicuous than the corresponding infections of walnut blight. When first observed in 1929, the author was informed that the blackening of the leaves and shoots had been noticed for some years and was a result, according to the orchardist, of the stunting effect of a cold and exposed situation. For young trees, fairly well cared for, the stunting was considerable. When it was realized however that the reverse was true, namely that the stunting was due to the blackening and that this was due to the presence of a parasite, the grower was ready to adopt more adequate control measures. Means similar to those which eventually proved satisfactory in the walnut disease were employed and have been reported to be giving equally encouraging results.

There can be little doubt that with young trees the pruning out of infected shoots and subsequent spraying with fungicides like Bordeaux mixture, applied early and with lime-sulphur applied later on, will prove effective in checking this decidedly serious disease under Tasmanian conditions. The advice given to the Hobart nursery included the above and in addition a warning about the probable dissemination by means of diseased layers taken from an infected " stool " which of course should not be used for propagation.

No fungal hyphae were found in the lesions, and none appeared on isolation plates. On the other hand bacterial pockets were constantly observed in sections of diseased tissue and the isolation plates always gave rise to bacterial colonies. No further work was done in connection with the disease and the diagnosis was founded upon the general symptoms, which agree with those given by Wormald (9) and Smith (4), and on the failure to obtain any evidence of the presence of a fungus parasite. The disease had already been recorded for South Australia by Osborn (10) in 1924.

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(*Received* 12 12/32.)

BOOK REVIEW.

STATISTICAL METHODS FOR RESEARCH WORKERS. By R. A. Fisher, D.Sc. Fourth Edition, pp. 307. Oliver & Boyd, 1932. 15s. nett.

It seems likely that to the historian of the future the outstanding feature of research work in the present decade will be the increasing demand for precision in all branches of science. The advances in this direction are well illustrated in the successive editions of Dr. Fisher's book, the fourth edition of which has now been issued.

The research worker of to-day is continually being faced with new problems; and it has been the business of the statistician to find methods with which to assist him in the elucidation of these problems.

The developments in horticultural science in the direction of precision have been certainly as rapid as any, considering the long-lived nature of the plants with which this branch of science is concerned. Horticultural workers in all parts of the world have not been slow to learn the more recent and exact methods of field trial arrangement and analysis on the one hand; and on the other, in almost every branch of fruit tree culture, efforts are being made to increase the uniformity of their material, by improved methods of propagation.

With many fruits, however, this last process is necessarily a slow one; and the outstanding problem at the moment is that of the best way to use existing, but often variable plantations to meet the more pressing demands of the grower for enlightenment.

The present edition of this book includes a section (49·1) in which is set forth a method, by which the preliminary yields of a plantation may be used to increase very greatly the precision of the results after the application of differential treatments.

Many of these variable fruit trees show a high positive correlation between successive years' cropping. This fact is utilized in this method; and in this way the forecast of the probable crop by the preliminary yields is used to check the subsequent differences in yield which may be associated with the treatments which had been applied.

It is noteworthy that this method can be applied to any of the modern methods of plot arrangement, and does not entail the dangerous expedient of equalization of preliminary yields, which is so often much less accurate than even a purely haphazard distribution of plots.

T.N.H.

R.